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OPTIMAL DESIGN OF SPARSE FIR FILTER USING GENETIC ALGORITHM

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ABSTRACT

Sparse design of FIR filter has been used for reducing the implementation complexity and computational cost. The objective of the sparse FIR filter design problem considered in this paper is to reduce the number of non zero-valued coefficients as well as optimization of the filter length. A novel algorithm i.e. Genetic Algorithm (GA) is proposed in this paper for the minimization of number of non-zero coefficients under the required filter order. An optimization stage is introduced to enhance the efficiency of the proposed method is evaluated through the example presented in the paper which gives better results than the existing technique. The number of non-zero coefficients is reduced by employing this method. Design results show the improvement in sparsity and also reduction in effective filter order.

KEYWORDS: sparse FIR filter , genetic algorithm (GA), effective minimum order, filter length, non-zero coefficients.

INTRODUCTION

FIR filters find a variety of applications in signal processing, communication field, image area and medical field. Traditional FIR filter design methods focus on reducing the implementation complexity. Extensive efforts have been made for the designing of FIR filter with power-of-two-coefficients [1], or making use of special structures, such as frequency-response masking technique [2] and sub expressions among filter coefficients [3], [4].

Lately, sparse representation come into existence and due to its emerging area of application, researchers pay more attention on the design of Sparse FIR filter. A sparse FIR filter is one which contains as few non zero-valued coefficients as possible. The major concern is on designing FIR filter with majority of coefficients being zero such that the additions and multiplications corresponding to zero-valued coefficients are omitted. As the arithmetic operations are reduced so the hardware required i.e. number of multipliers and adders is minimized which leads to reduction in implementation complexity and computation cost. Sparse Filter design uses l_0 (quasi)-norm problem for reducing the number of non-zero coefficients. However, the design problem of minimizing l_0-norm of filter coefficients is highly non-convex as the positions of zero-valued coefficients are not specified. An algorithm is presented in [5] to design half band filter. The design problem is casted as a mixer integer linear programming (MILP) which is further solved by branch and bound technique. The p-norm minimization problem is used in [6] for the design of Sparse FIR filter. Where p is gradually decreasing from 1 toward 0. Another design strategy is presented in [7] which is based on linear programming. In this, two approaches are used for the design of Sparse FIR filter 1. Minimum-increase 2. Smallest coefficient. The first approach gradually nullifies the filter coefficients and second approach eliminates the non zero-valued coefficients. To tackle the non-convexity design problem, an efficient method is employed in [8]. In this, the l_1-norm based optimization technique is used with small magnitude coefficients forced to 0 and minimizes the maximum approximation error. In [10], [12], an iterative design strategy is employed. The algorithm is inspired by iterative shrinkage/thresh holding technique. The method proves to be efficient one but in previous papers, the better results are obtained at a cost of higher delays. In [14], a joint attempt is presented to reduce the non zero-coefficients as well as to optimize the filter length. The effect of filter order on the design performance is evaluated in [14]. In this iterative-reweighted-least-square (IRLS) algorithm is used to solve the optimization problem. For further improvement in the design results, an efficient design method will be developed in this paper. For the design of Sparse FIR filter, Genetic Algorithm (GA) is to be used for improving the sparsity in the filter coefficients obtained by suitable filter design method. In section II the problem is formulated and GA is applied and the proposed algorithm is explained in this section. Design results are compared with other algorithms in section III and conclusion is given in section IV.

PROBLEM FORMULATION

For an FIR filter of order N, the number of coefficients and the filter order is related as

$$N=M-1 \qquad (1)$$

For filter structures of very large length, the implementation becomes difficult. The length of the filter is determined from the number of coefficients in filter realization. To reduce this implementation complexity and the hardware required i.e. number of adders and multiplies sparseness is to be introduced in the filter coefficients. The objective of the proposed method is to improve the sparsity of filter coefficients in comparison to previous researches. The number of non-zero coefficients is to be reduced further than obtained in [7], [14] along with efficient filter length i.e. minimum filter order (N_{min}).

Proposed work

Suppose an FIR filter (Type I) of order N and length (N+1) is under consideration. Firstly, FIR filter is designed in optimal sense using Parks-McClellan method. In Parks-McClellan method, FIR filter is represented as

$$H(w) = \sum_{k=0}^{n} h_k \cos(wk) \qquad (2)$$

It is an iterative method for finding the optimal Chebyshev finite impulse response (FIR) filter. The objective of this method is to minimize the error in the pass band and stop band by using Chebyshev approximation. For a real set $F \subseteq [0, \pi]$, consider a continuous function

$$D(w), w \in f \quad \min \delta$$

such that (3a)

$$\|E(w)\| = \max_{w \in F} \left| W(w)(H(w) - D(w)) \right| \leq \delta \qquad (3b)$$

Where *W(w)* is real valued weight function which is set to some constants (generally 1) for pass band and stop band but 0 in transition bands. Hence, filter coefficients are obtained using this method.

To begin with sparse filter design it is required to make some coefficients zero. For this, a balance needs to be maintained between the sparsity and the performance of the filter. Now, suppose L number of coefficients out of N+1 is to be made zero-valued under some frequency specifications (δ). Hence, the objective is to maximize L under the frequency constraint (δ). For this, an efficient optimization algorithm is introduced to obtain optimal solutions. In this paper, Genetic Algorithm is used for this purpose. Once the positions of L zero-valued coefficients are specified, then these positions are encoded as the genes of a chromosome .GA starts working with the population of the chromosomes. Each chromosome represents a set of zero-valued coefficients' positions.

Encoding

The choice of encoding is the most important factor in designing a genetic algorithm. For the proposed work, integer encoding is used.

index	1 2 3 4……………………L/2
Chromosome 1	6 2 12……………………8
Chromosome 2	4 3 13……………………15

Fig 1: Encoding of chromosomes

The basic steps involved in GA operation are explained below:

1. Population Initialization
   GA starts when a random initial population is created. The population Size can be variable but generally fixed.

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2. Fitness function
   After creating population, the fitness level of the individuals in the population is evaluated by using a fitness function. The fitness function is usually an objective and measured the quality of the represented solution. The fitness function is usually measured by calculating r.m.s.e. value ($\frac{\sqrt{(X'-X)^2}}{N+1}$).
3. Selection
   The best fitted individuals are selected to breed new generation. Then the genetic operators are used for evolution from generation to generation by altering genetic material contained in the chromosome strings of fit individuals. The basic GA operators are crossover and mutation.

4. Crossover
   Genetic material from the selected individuals is recombined to form one or more offspring where some of the useful characteristics of the parents are preserved. So, new chromosomes are generated that are more fit than their ancestors. The probability of crossover is usually 60% to 70%.

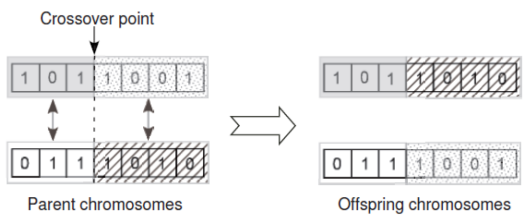

Fig 2: A typical one-point crossover in binary representation

5. Mutation
   It is a random process where one allele of a gene is replaced by another to produce a new genetic structure. This generational process is repeated until termination condition is achieved i.e. maximum number of iterations.

The basic steps of a genetic algorithm are shown through a flow chart given below:
GA Flow Chart:

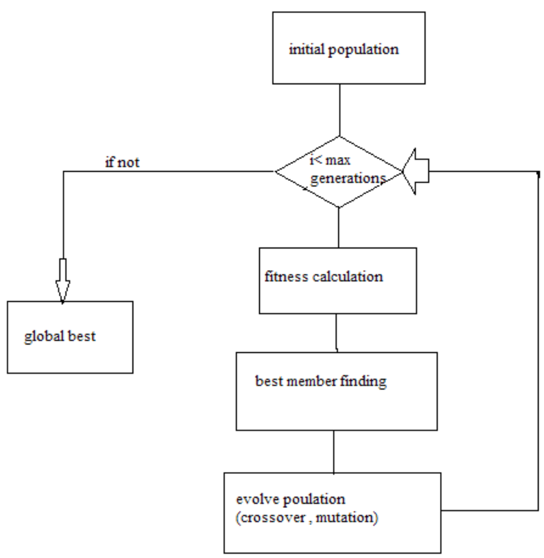

Fig 3: Flow Chart of Genetic Algorithm

SIMULATION AND RESULT

To illustrate the performance of the proposed method, an example taken from existing popular algorithm on sparse filter design is examined. A Low Pass filter of Type I is designed using PM method and then Genetic Algorithm is applied to generate sparser results. For simulation of the above example on software, MATLAB is used. A Low Pass FIR filter is designed in sparse sense in proposed work. Filter Specifications are given in Table I

Table I: Design Specification

Passband region	{0, 0.0436π}
Stopband region	{0.0872π,π}
Filter Order	100
Passband magnitude	Within ±0.5dB of unity
Stopband magnitude	Below -35dB

In the proposed system model, firstly a Low Pass FIR Type I filter is designed optimally using best suitable Parks-McClellan method. For a filter of order N=100, pass band and stop band regions are specified in the table above. This method minimizes the error in the pass band and the stop band by using Chebyshev approximation. When the filter designing process is done, the sparse entries are introduced in the filter coefficients by optimization algorithm. For a filter with filter order N=100, assuming L out of N+1 entries are to be made zero GA starts its working. For this example the population size is set to 100. In the first step initial population is created by the genetic algorithm by considering the filter coefficients obtained by the above design method. Then the fitness of each individual is evaluated for the population. After calculating the fitness, best member is find out and then new generation is breed to generate offspring. For this process crossover rate is set to 0.7. Then again new fitness is calculated from the offspring generated above. This process is repeated until termination condition is achieved i.e. δ (threshold value) is achieved. Maximum generations evolved during this algorithm are 42. Results obtained from the proposed work are listed in the Table II and results obtained by this method are compared by the previous researches also. The number of non-zero coefficients obtained by the three different methods is listed in this table. The number of non-zero coefficients is calculated by adding 1 to filter order N then subtracts the number of zero-valued coefficients obtained by the algorithm. The minimum filter order N_{min} achieved by different algorithms is also given in the Table II. From the design results obtained, it is observed that with the proposed algorithm the number of sparse entries is increased means the number of non-zero coefficients is reduced in comparison to [14] and [7] and the filter is efficient in the sense that minimum filter order achieved is also improved as compared to [14] and [7]. The process of genetic algorithm is shown in fig 4. The magnitude response of sparse filter obtained by GA in this example is also shown in fig 5.

CONCLUSION

This paper proposed an efficient method for the design of Sparse FIR filter under given specifications. A genetic algorithm is used to obtain the desired results. This method is capable of decreasing the number of non-zero coefficients as compared to previous approaches as well as determines the minimum filter order.

Table II. Design Results obtained from Example

	N_{min}	L_{NZ}
Proposed algorithm	66	53
IRLS [14]	76	55
Minimum *l*-norm [7]	78	65

GENETIC ALGORITHM

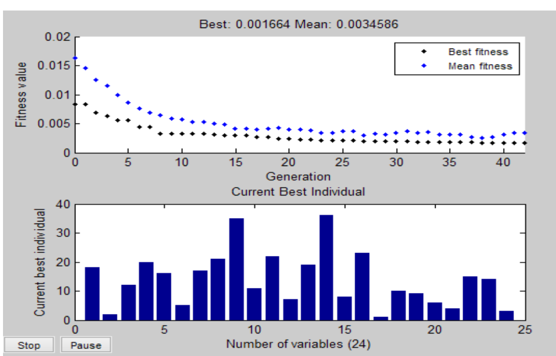

Fig 4: Genetic algorithm

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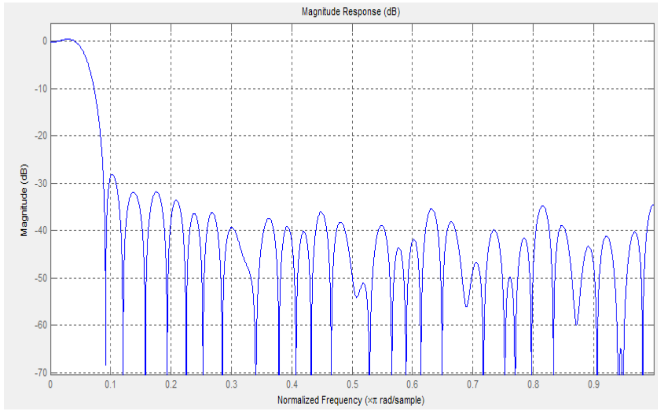

Fig 5: Magnitude response of sparse filter obtained by GA in Example

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