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Design of Low Power FIR Filter Coefficients Using Genetic Algorithm (Optimization)

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ABSTRACT

With the explosive growth of wireless communication system and portable devices, the power reduction has become a major problem. Many of the communication system today utilize digital signal processors (DSP) to resolve the transmitted information. Finite impulse response (FIR) filters have been and continued to be important building blocks in many digital processing systems (DSP). Hamming distance is a measure of switching activity corresponding to the number of energy consuming transition in multiplier and accumulate (MAC) of filter while implementing on digital signal processors (DSP). The hamming distance between consecutive coefficient values and the number of signal toggling in opposite directions thus forms the measure of bus power dissipation. Genetic algorithms can implemented as a computer simulation in which a population of abstract representations (called chromosomes or the genotype or the genome) of candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem evolves toward better solutions. In this paper the hamming distance of fir filter is minimized by minimizing the switching activity using "Genetic Algorithms" optimization technique to reduce the power dissipation and to increase the battery life of portable multimedia devices.

1. INTRODUCTION

A major problem associated with increases in the processing power and the sophistication of signal processing algorithms is the increasing levels of power dissipation.

1.1. Low Power Design Methodology

An optimization that could be done at this level is driven by voltage scaling. It is necessary to scale supply voltage for a quadratic improvement in energy per transition. Unfortunately, we pay a speed penalty for a V_{dd} reduction with delays increasing, as V_{dd} approaches the threshold voltage of the devices. The simple first order relationship between V_{dd} and gate delay, t_d for a CMOS gate is given in (1.1),

$$t_d \propto \frac{1}{(V_{dd} - V_t)^2} \quad (1.1)$$

The objective is to reduce power consumption while keeping the throughput of the overall system fixed.

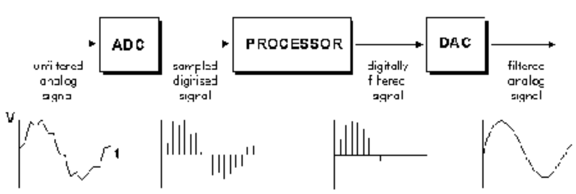

Fig 1: Implementation of Filter on Digital Signal Processor

An optimization or a mathematical programming problem can be stated as follows:

Find $X = [x_1 x_2 x_3 \ldots\ldots x_n]$

Subjected to the constraints

$g_j(X)$ £ 0. $j = 1, 2 \ldots\ldots\ldots\ldots m$

$hj(X)$ £ 0. $j = 1, 2 \ldots\ldots\ldots\ldots$ p

Where X is an n-dimensional design vector, $f(X)$ is termed the objective function and $g_j(X)$ and $h_j(X)$ are known as inequality and equality constraints, respectively.

2. OBJECTIVE

Finite Impulse Response (FIR) filter is implemented as a series of multiply and accumulate operations on a programmable Digital Signal Processor (DSP). The multiply and accumulate (MAC) unit of a digital signal processor experiences high switching activity due to signal transitions which results in higher power dissipation. Hamming Distance forms a measure of the switching activity during implementation of the filter. The Objective of the paper is to minimize the Hamming distance and reduce the signal toggle by using optimization technique, Genetic Algorithm (GA), so that its power dissipation is reduced while its implementation on a Digital Signal Processor.

The purpose of the optimization is to choose the best one of many acceptable designs available. Thus a criterion has to be chosen for comparing the different alternative acceptable design and for selecting the one. The criterion, with respect to which the design is optimized, when expressed as a function of the design variables, is known as objective function. If $f_1(X)$ and $f_2(X)$ denote two objective functions, a new objective function for optimization is constructed as

$$f(X) = a_1 f_1(X) + a_2 f_2(X)$$

where $f(X)$ is a new objective function, a_1 and a_2 are constants whose values indicate the relative importance of one objective function relative to the other.

Description

Genetic Algorithm is an emerging optimization algorithm for signal processing and considered a powerful optimizer in away areas. The GA has been demonstrated a powerful method for these multi objective problems, enabling to obtain the pareto optimal set instead of single solution. Genetic Algorithms (GAs) were invented by John Holland and developed by him and his students and colleagues.

Search Space

The space of all feasible solutions (the set of solutions among which the desired solution resides) is called search space (also state space). Each point in the search space represents one possible solution. Each possible solution can be "marked" by its value (or fitness) for the problem. With GA we look for the best solution among a number of possible solutions - represented by one point in the search space.

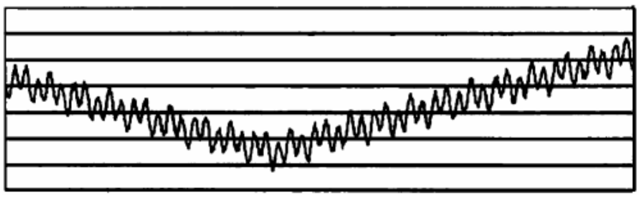

Fig 2: G.A. Search Space

Working Principle

To illustrate the working principle of GA consider a unconstrained optimization problem

Maximize $f(X)$

$X_i^L \leq X_i \leq X_i^U$ for $i = 1, 2 \ldots N$

If $f(X)$, for $f(X) > 0$ is to be minimized, then the objective function is written as maximize

$$\frac{1}{1+f(x)}$$

Encoding: Since genetic algorithms search directly in the solution space, it needs a way to encode solutions in a way that can be manipulated by the genetic algorithm.

Binary Encoding: In binary encoding, every chromosome is a string of bits - 0 or 1.

Table1
Chromosomes with Binary Encoding

Chromosome A	101100101100101011100101
Chromosome B	111111100000110000011111

Permutation Encoding: In permutation encoding, every chromosome is a string of numbers that represent a position in a sequence.

Table 2
Permutation Encoding

Chromosome A	1 5 3 2 6 4 7 9 8
Chromosome B	8 5 6 7 2 3 1 4 9

3. RANK SELECTION

Rank selection ranks the population first and then every chromosome receives fitness value determined by this ranking. The worst case will have the fitness 1, the second worst 2 etc. and the best will have fitness N (number of chromosomes in population).

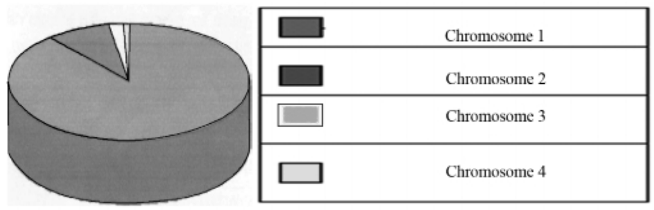

Fig 3: Situation before Ranking

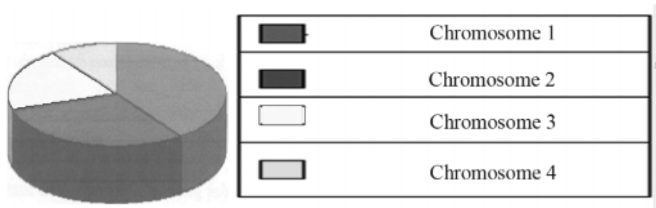

Fig4: Situations After Ranking (Graph Of Fitness)

Hamming Distance Minim. Algorithm

Problem Definition: The Hamming distance minimization problem using Steepest Decent approach stated as follows For a Given N-tap FIR filter with coefficient A, $i = 0, N - 1$ i that satisfy the filter response in terms of pass band ripples, stop band attenuation and linear phase, find a new set of coefficient A, $i = 0, N - 1$ i such that the total Hamming distance between successive coefficients is minimized while still satisfied the desired filter characteristics in terms of pass band ripple and stop band attenuation.

Coefficient Sealing: The first phase of the algorithm involves uniformly scaling the coefficient so as to reduce the total Hamming distance between successive coefficients. For N-tap filter with N coefficients (A, i = 0, N – 1), the output Y (n) is given by equation.

$$Y(n) = \sum_{i=0}^{N-1} (A_i * X_{n-1})$$

Genetic Algorithms are successfully used for the design of FIR filters. The problem is formulated as error minimization between the Ideal frequency response and the desired frequency response as per the design specification in terms of pass band ripple, stop band attenuation and linear phase. Here one more objective added is the Hamming distance between the successive values of the designed filter should be minimum than the ideal filter coefficients. As the Hamming Distance is the measure of the signal switching activity it should also be minimized to reduce the power dissipation in the multipliers while implementing the FIR filtering operation on digital signal processors. So the problem is multi objective optimization problem and it is solved by using weighted sum approach, converting the problem into single objective by assigning the appropriate weights. The problem is then solved using Genetic Algorithms.

4. SOLUTION METHODOLOGY

The intent of work is to optimize the coefficients of FIR filter, to minimize the Hamming distance and satisfying the desired filter characteristics in terms of pass band ripple and stop band attenuation.

The multi objective problem of minimizing the Hamming distance and mean square error is converted into a scalar problem by constructing a weighted sum of the objectives to generate Pareto optimal solution. The Pareto optimal solutions for different simulated weight combination are generated considering both the objectives simultaneously. To simulate weight combination, weights $w_{i,}$ I = 1, 2……. L are varied from 0.1 to 1.0 in steps 0.1, so that their sum is 1.0. The weighting coefficients w_1 and w_2 are used to select of error and Hamming distance. The weighted objective function is written as

$$F = w_1 f_M + w_2 f_H$$

Here f_M and f_H are the fitness functions for Mean square error and Hamming distance. The scalar optimization mentioned above is solved using Genetic Algorithm the random number population is generated and the chromosomes are selected based upon the maximum fitness of the fitness function using the roulette wheel selection. The Genetic operator's crossover and mutation are applied; uniform crossover is applied at the defined in a mating pool to produce the new generation which are maximally fit.

Methodology / Planning of Work

The Hamming Distance minimization problem is formulated as a local search problem, where the optimum coefficient values are searched in their neighborhood. This is done by using an iterative improvement process. During the each iteration one or more coefficients are suitably modified so as to reduce the total Hamming distance while still satisfying the desired filter characteristics. The optimization process continues till no further reduction is possible.

The coefficient optimization is done in two phases:

In the first phase, all the coefficients are scaled uniformly. The advantage of such an approach is that it does not affect the filter characteristics in terms of pass band ripples and stop band attenuation and phase response. The sealing results in the same gain / attenuation ratio.

In the second phase of optimization one coefficient is perturbed in the each iteration. In case of requirement to retain the linear phase characteristics, the coefficients are perturbed in pairs (Ai and An-1-i) so as to preserve coefficients symmetry. The selection of coefficient for perturbation and the amount of perturbation has the direct impact on overall optimization quality. Various strategies can be adopted for coefficient perturbation. The strategies adopted here include 'Genetic Algorithms'. The Genetic Algorithms are the evolutionary algorithm which generates the random numbers and selects the best fit value according to the fitness function and search the whole space to find the global value.

Simulation Results

Output of the 'C' Programme for Clculating Hamming Distance

Enter the no. of Parameters: 8

Enter the Values of Parameters in Fraction.....

.1234

.2345

.3456

.4567

.5678

.6789

.7890

.8901

The values of parameters are:

0.123400 0.234500 0.345600 0.456700 0.567800 0.678900 0.789000 0.890100

Truncated values are following:

0.123400

0.234500

0.345600

0.456700

0.567800

0.678900

0.789000

0.890100

0.345600

0.456700

0.567800

0.678900

0.789000

0.890100

Binary equivalent of entered coefficients

BINARY EQUIVALENT OF 0.123400 IS 111110/10 TO POWER 9

BINARY EQUIVALENT OF 0.234500 IS 1111000/10 TO POWER 9

BINARY EQUIVALENT OF 0.345600 IS 10110000/10TO POWER 9

BINARY EQUIVALENT OF 0.456700 IS 11101000/10TO POWER 9

BINARY EQUIVALENT OF 0.567800 IS 100100010/10TO POWER 9

BINARY EQUIVALENT OF 0.678900 IS 101011010/10TO POWER 9

BINARY EQUIVALENT OF 0.789000 IS 110010010/10TO POWER 9

BINARY EQUIVALENT OF 0.890100 IS 111000110/10TO POWER 9

EXOR OF 0.123400 AND 0.234500 IS 1000110/10 TO POWER 9

EXOR =70\N

NUMBER OF ONES =3

Similarly other calculations for Number of Ones can be done. Thus

Total Hamming Distance among the Filter Coefficients = 24.

OUTPUT OF MATLAB DESIGNING CODE FOR WINDOWS:

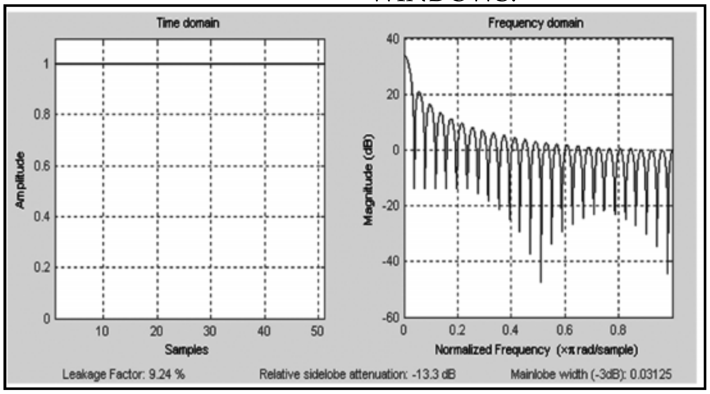

Fig 5: Rectangular Window in Matlab

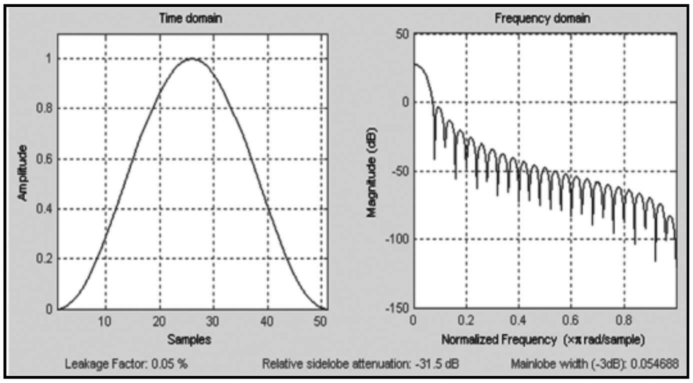

Fig 6: Hamming Window in Matlab

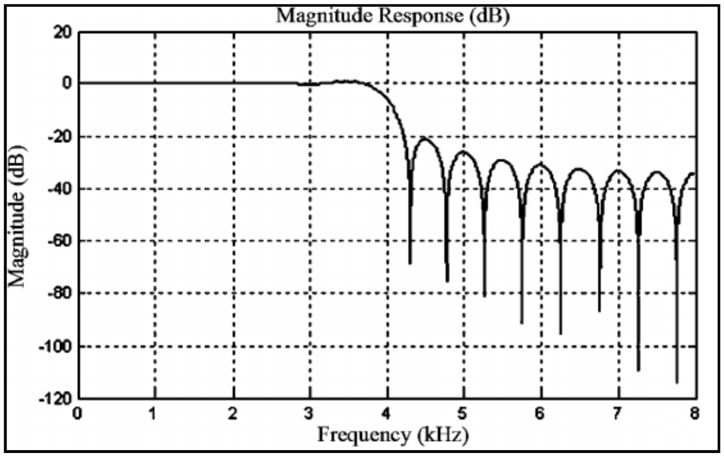

Fig 7: Low Pass Filter Normal Response

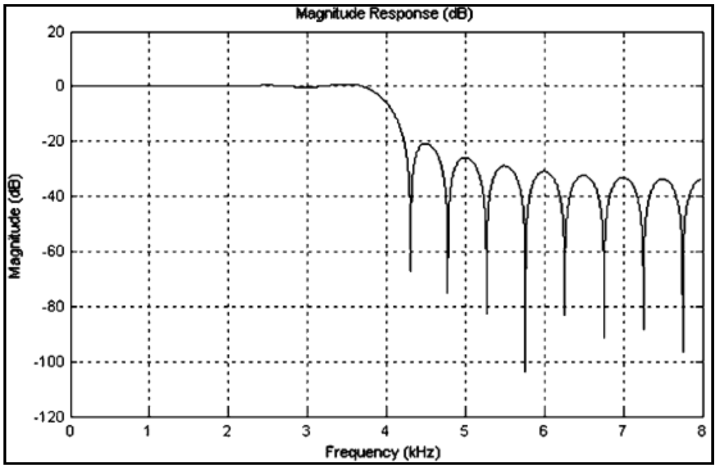

Fig 8: Response with Genetic Algorithm

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