Effective Approach for Reducing Complexity in FIR filters

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Abstract- In modern world Digital Signal Processing (DSP) is a prominent one. Finite Impulse Response (FIR) filters are widely used in DSP applications because of its stability and linear phase. Multipliers in the FIR filter are realized using combination of shifters and adders. The usage of adders in the filter structure is high, so the complexity increases. The Canonic Signed Digit (CSD) representation is used to minimize the number of adders in the FIR filter. Mixed Integer Linear programming (MILP) is an algorithm developed to optimize the coefficients in the FIR filter by traversing Discrete coefficients and number of adders used are still further reduced. The low complexity and high performance linear phase FIR filter can be achieved. And comparison is made with the conventional method and result is shown.

I. INTRODUCTION:

Digital Signal Processing (DSP) techniques used in many applications such as digital communications and science fields. Digital filters are basic element in DSP systems. There are two types of digital filters: Finite Impulse Response (FIR) filters and Infinite Impulse Response (IIR) filters. Since FIR filters possess many important features such as exact linear phase property, guaranteed stability, free of limit cycle oscillations, and low coefficient sensitivity, it is widely used in many applications. FIR filter performs convolution operation as weighted sum of input sequences. The general FIR filter can be described as

$$\text{(1)}$$

Where M is the number of tap used in the FIR filter. C_k are the filter coefficients and $X(n-k)$ is the input sequences. The multiplication operation is used in FIR filtering. Since coefficient multiplier is complex, slowest component, power hungry and it occupies large silicon area. To address the above problems, considerable efforts have been made on reducing the complexities and power consumptions for the DSP systems.

The complexity can be reduced by reducing the word length of the coefficients. The most efficient way to represent the coefficient in minimum word length is by using Signed Power of Two values (SPT). By Signed power of two values, FIR filter can be realized purely as a multiplier less technique.

Therefore, the Multiplication operation is replaced by shifters and adders. The complexity of a filter is determined by using number of adders or subtractors used in the filter coefficient. The complexity also increases in the multiplier less technique because number of adders used is high.

The common subexpression elimination is an algorithm used to find the common subexpression in the filtering operation. The common subexpression can be used whenever it is required. The SPT values in the coefficients are grouped together to form the common subexpression. As we know, the complexity of the filter depends upon the number of adder used. The minimum number of SPT values will have minimum number of adders in the filter structure. The maximum number of SPT values will have maximum common subexpression, so the adders are reused. The canonic signed digit representation (CSD) is one of the minimum representations used to reduce the number of adders in the filter structure. Mixed integer linear programming (MILP) is used to optimize the filter coefficients by searching the discrete one.

II. RELATED WORK

A. SPT values:

One of the most successful strategies is to optimize the filter coefficients in SPT values, where each coefficient is represented as a sum of a limited number of SPT values [2]. It is well known that an integer can be represented in SPT number space as,

$$\text{(2)}$$

where, $I = 0$ to $k-1$

where k is the number of SPT terms, $q(i)$ is a non negative integer, and the term $y(i)$ lies between $\{-1,1\}$. The SPT values should not possess any two consecutive non zero digits. It contains only digits 1, 0 and $\bar{1}$. Where $\bar{1}$ represents -1. Example 101, 1001001 are SPT numbers because there are no consecutive nonzero digits and 0110111 is not an SPT number because there is an occurrence of consecutive nonzero digits.

B. Canonic Signed Digit (CSD) Representation:

The CSD format is similar to SPT term. It encodes a binary number to a fewest number of nonzero bit [3].Like SPT, CSD uses three digits 0, 1, and -1.It is one of the minimum representation used in filter coefficient synthesis. The number of partial products is proportional to the number of nonzero bits in the filter coefficient. If the nonzero bits are high, the number of partial product also increases; therefore filter becomes complex and more power consuming. So the CSD is used to minimize the number of nonzero bits. The CSD uses N/2 number of nonzero bits, and they are rounded to the nearest integer value. Where N is the number of bits in the coefficient. Conversion of two's complement to CSD representation is given in the flow chart Fig.1 shown below. To convert two's complement number to CSD format a carry is propagated from LSB to MSB. The CSD values thus obtained should be multiplied with the input, so the CSD multiplication is implemented using Horner's rule. The multiplier contain set of coefficients, each coefficients are multiplied with the input sequence by the multiplier, which is a combination of shift and add operation. Efficient implementation of filter in CSD representation will reduce the number of adders used.
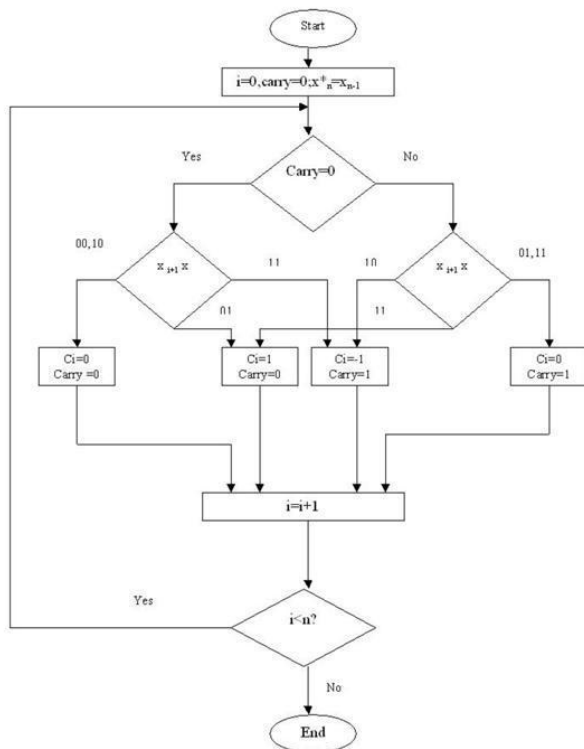

Figure 1. Two's complement to CSD conversion *C. MILP*

The Mixed integer linear programming(MILP) is used to optimize the filter coefficient still further[6]. Mixed integer linear programming (MILP) is the technique employed to optimize the filter coefficients to meet the given specifications. In this technique, the frequency response ripple is minimized subject to a given number of adders. The obtained results may not be the optimum in terms of the number of adders, but the

saving in the number of adders can be achieved by using this technique is significant compared with those obtained using other techniques that can be used to design filters with respectable length and bit width. The computation time needed to optimize a filter with order 60 and coefficient bit width 12 is typically within a few minutes to a few hours.

Mixed Integer Linear Programming is capable of traversing the entire discrete solutions efficiently for a given wordlength, during the traverse the optimality of the synthesis of a set of discrete coefficients is monitored and flagged by a "Certainty" whenever a new coefficient is discretized. In this manner, when the traverse is completed then the algorithm is able to be aware of whether an optimum solution is obtaibed.Major aim of this algorithm is capable of designing FIR filters with minimum number of adders.

The general steps of the filter design problem using MILP, are given as follows:

   i.   formulation the filter optimization problem;
   ii. obtaining the continuous optimum solution;
   iii. choosing the effective wordlength (EWL);
   iv. traverse of the discrete solutions.

D. Optimizing Filter Coefficients Using MILP

The frequency response of a linear-phase FIR filter of length N for Zero Phase can be expressed as,

$$\tag{3}$$

Where, n = 0 to N-1/2

where, h(n)'s are the filter coefficients and Trig(ω, n) is a trigonometric function depending on the value of N and the symmetry of the impulse response.

For a given set of filter specifications such as passband edge, stopband edge, passband and stopband ripple ratio, and filter length N, the optimum continuous coefficients minimizing the magnitude ripple can be found by formulating the problem as a linear programming problem and this is given by

Minimize: δ subject to:
$1- \delta \leq H(\omega) \leq 1+\delta$
for $\omega \, \varepsilon \, [0, \omega_p]$
$-\delta_s \, \delta_{\,/} \, \delta_p \leq H(\omega) \leq \delta_s \, \delta_{\,/} \, \delta_p$
For $\omega \, \varepsilon \, [\omega_{s,}\pi]$

To find the coefficient values in a discrete space for the same set of filter specifications, the linear programming problem is replaced by a MILP problem. Branch and bound algorithm is one of the most efficient techniques to solve MILP problem. Branch and bound (BB or B&B) is a general algorithm for finding optimal solutions of various optimization problems, especially in discrete and combinatorial optimization.

III. METHODOLOGY USED

Following are the steps depict the procedure exactly done

i. Filter specifications are defined such as order, Stop band frequency, Pass band frequency, Stop band attenuation and Pass band attenuation.
ii. Calculate the filter coefficient using MATLAB FDA Tool.
iii. CSD algorithm is applied on filter coefficients
iv. Design multiplier using Horner's rule for sub expression elimination.
v. MILP is applied for optimization.
vi. Implement in FIR structure.
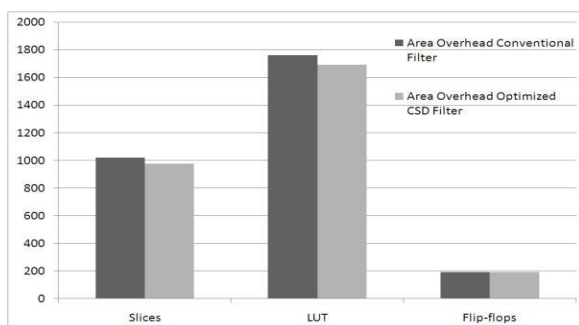vii. Compare with conventional filter structure

IV. SIMULATION RESULTS AND CONCLUSION

In canonic signed digit representations, the areas in terms of number of slices are optimized. When we go for mixed integer linear programming (MILP) the area can be still further reduced in terms of number of slices. Hence minimum numbers of adders are used for implementation of FIR filter. Thus the complexity is reduced and performance is also enhanced. The simulation results are given below for the design of 10 tap FIR filter .The comparison results are shown below for filter design using CSD and conventional design. Hence MILP is in process. Table 1.Simulation Results

Components	Area Overhead	
	Conventional Filter	Optimized CSD Filter
Slices	1019	977
Flip-flops	193	193
LUT	1759	1691

Comparison of conventional filter optimized filter
Fig. 2: Comparison of area overhead.

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