The Appliance of Genetic Algorithm in Adaptive Moving Target Indicator Filter Design

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Abstract- **The traditional non-recursive MTI filter has wide application in radar systems because of its simple structure and low amount of calculation. However, it obviously has some disadvantages, such as the narrow distance in Doppler frequency domain between slow speed targets and ground clutter. Without attenuating target signals, it's hard to effectively suppress clutter. The problem can be solved by adopting the recursive MTI filter. Applying genetic algorithm and the optimized fitness function, the proposed adaptive recursive MTI filter can significantly improve some parameters like improvement factor, passband bandwidth, and passband ripple.**

Index terms- **genetic algorithms; adaptive recursive MTI filter; fitness function**

I. INTRODUCTION

In a radar system, the purpose of applying MTI filter is to eliminate the stationary clutter around zero frequency. Therefore, the stop band of MTI filter should be in zero frequency or in PRF (Pulse Repetition Frequency) multiples, namely, within the range frequency of strong clutter. Typically, MTI filters have linear transversal structure when the interfering signal is assumed as Gaussian distribution. In reality, the non-recursive MTI filter is often composed of some single cascaded cancellers, and its transfer function is:

$$H(z) = \left(\frac{z-1}{z}\right)^{n-1} \tag{1}$$

Its weighting coefficients are the familiar binomial coefficients:

$$a_k = \frac{(-1)^k n!}{K!(n-k)!} \tag{2}$$

Although non-recursive MTI filter has excellent transient characteristics, it usually has a narrow passband and wide zones of inhibition. If MTI filter is used to have a relatively better performance on passband, a recursive MTI filter can be considered because, in theory, it's possible to synthesize almost any velocity response curve with this kind of MTI filter. Compared with the non-recursive filters, the recursive ones also have shortcomings, for example, the system may not be stable, and the flexible design methods are lacking.

In this paper, a method to design adaptive recursive MTI filters is presented. It not only can ensure the stability of the system, but also has such advantages as excellent IF and light computation burden in real time. The design detail is presented in the next part. Then, an example of design and conclusions are given.

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II. THE DESIGN CRITERIA OF AN ADAPTIVE RECURSIVE MTI FILTER

The adaptive filter can be trained by the samples according to some algorithms to continuously adjust the weighting coefficients, so that the value of the mean square error between the actual output and the ideal output is minimized. The genetic algorithm is a highly parallel adaptive search method with strong versatility, and it basically does not restrict the optimization parameters, which means global optimal solution can be obtained. So, here the genetic algorithm is applied to find the optimized weighting coefficients of adaptive recursive MTI filter.

The design idea of this paper is to make non-recursive MTI filter to be recursive MTI filter by adding feedback, where the coefficients of the feedback can be changed adaptively by genetic algorithm. Taking the complexity and stability of the system into consideration, here seven parameters are designed, three of which are the feedback parameters. Namely, the structure of the filter is as shown in Figure 1.

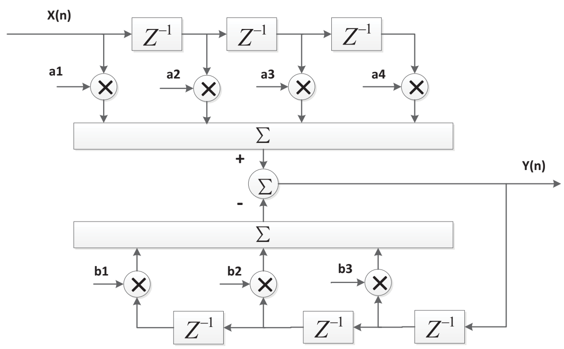

Figure 1. The structure of recursive filter

Based on the fact that a non-recursive MTI filter is often composed of some cascaded cancellers, and according to equation (2), the values of a1, a2, a3, a4 are 1, -3, 3, 1 respectively. The parameters of the feedback are b1, b2, and b3. The main purpose of this paper is to achieve the optimal performance of MTI filter by changing the value of the feedback coefficients adaptively.

The frequency response of the filter in Figure 1 is:

$$H(e^{j\omega}) = \frac{1-3e^{-j\omega}+3e^{-2j\omega}-e^{-3j\omega}}{1+b_1e^{-j\omega}+b_2e^{-2j\omega}+b_3e^{-3j\omega}} \tag{3}$$

In practice, the most important performance indicators of MTI filter are improvement factor (If), passband bandwidth (B_P), and passband ripple (δ_P), which are mutually exclusive. So a compromise is considered to achieve a balanced state where the three of the most important indicators have brought about excellent performance of the system.

III. The Application Of Genetic Algorithms In Feedback Coefficients Design

In a genetic algorithm (GA), the first and also very crucial step is to determine the fitness function because the function is an important link between GA and a real system. While designing the feedback parameters, the main goal is to achieve a relatively high If , a broad with of passband (B_P), and a small ripple of passband (δ_P). Then the fitness function ($F(s)$) is designed as:

$$F(s) = \arctan(If - If\_s)/\pi + 0.5 + B_p + \arctan(1/\delta_p)/\pi + 0.5 \tag{4}$$

where If_s refers to the actual improvement factor value required to be achieved. $B_p = \left[b_1, b_2, b_3\right]$ is the feedback coefficient vector. In the equation (4), we did some transformation and then added the three indicators together. The aim is to make the scope of the all three indicators (0, 1), which means they will achieve the same degree of influence. In practical application, each component of the vector B_P is encoded with ordinary binary. The specific procedures of the algorithm are:

1. Initialization: randomly create an initial population, which contains L chromosomes, and the i-th chromosome is $[b_{i1}, b_{i2}, b_{i3}]$, where $b_{ik}\,(k = 1, 2, 3)$ is known as a gene.

2. Reproduction: firstly, calculate the corresponding values of If , B_p , and δ_p of each chromosome in the j-th generation of the population. If these values can meet the requirement, then calculate the value of the fitness function; if not, apply punishment to redefine the fitness function of the chromosome. To be specific, the punishment is like this: take If as an example, if $If < If\_s$, then shrink the first item of equation (4) 100 times, so that the fitness value of the chromosome also will be smaller. For the other two parameters (B_p and δ_p), it is the same way. After this, the roulette method is applied according to the fitness value of each chromosome, and then the next-generation population will be formed.

3. Crossover: the purpose of this operation is to allow the offspring to produce better individuals. First the chromosomes of the population are divided into two parts according to their fitness values. Chromosomes with high fitness values will be in the elite part, the rest of which will be in the non-elite part. Crossover probability is P. The crossover operation is performed separately in the two sections.

4. Mutation: it means flipping the value of a bit on the gene of one chromosome in accordance with the mutation probability, namely, 1 becomes o, while 0 becomes 1. In practical applications, in order to achieve a fast algorithm convergence, a larger mutation probability P_b is used when all the three indicators meet their requirements. If, on the other hand, any one of them can't meet the need, then a smaller mutation probability P_s is used.

5. After all the operations are finished, the next generation population is obtained. At this time if the number of iterations reaches a preset value m, then stop the operation, and output the values of the chromosome and the corresponding value of fitness function. The chromosome with maximum fitness is the optimal solution chromosome. If that is not the case, then let m = m +1, return to the second step and continue the operation.

6. System stability inspection: if the poles of MTI filter are all inside the unit circle, then the system is stable; otherwise we return to the first step.

VI. Simulation Example

Here a MTI filter is designed and applied to the train radar. Assume that the radar antennas transmit power is of Gaussian distribution, and the pitch angle of the antenna is approximately equal to 0, then the clutter spectrum, when the train is moving, is:

$$S(f) = P\exp(-f^2/2\sigma_c^2)/\sqrt{2\pi\sigma_c^2} \tag{5}$$

where $\sigma_c = 0.3 f_c$, $f_c = \frac{2v}{\lambda}\theta_B \sin\theta$, v stands for the speed of the train, λ is the wavelength of the transmission signal, P is a constant, θ is the antenna azimuth angle, and θ_B is the width of the antenna beam.

The specific simulation parameters are: $v = 20m/s$, $\lambda = 0.03m$. When the widest clutter is considered, $\theta = 90^o$ and $\theta_B = 1.5^o$. The noise power spectral simulation is shown in Figure 2:

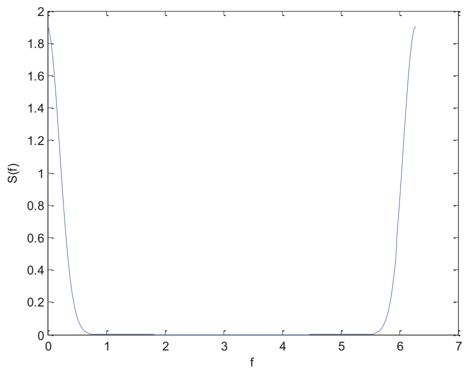

Figure 2. Noise power spectrum

The system is supposed that the radar pulse repetition frequency is 1000 kHz, the improvement factor (If) needs to be at least 55dB, passband bandwidth (B_p) needs to be above 0.64, and passband ripple (δ_p) should be less than 2dB.

Genetic algorithm parameters is set that crossover probability $P_c = 0.8$, mutation probability $P_b = 0.3$, $P_s = 0.01$, the number of chromosomes in each population is L = 100, the number of iterations is 100, and the code length is 32.

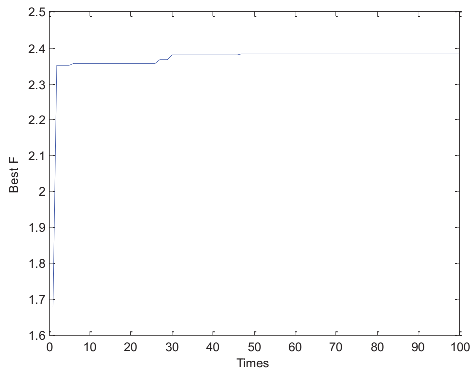

Figure 3. Value of the fitness function

As the algorithm goes on and the feedback parameters continue to be optimized, the performance of the designed filter is improved, which is quite obvious if we pay attention to the changes in the value of fitness function. In figure 3, it can be seen that the value of fitness function increases continuously, reaches a maximum, and then tends to be stabilized. Hence, the performance of the designed filter has reached the best within all requirements mentioned above.

After the whole genetic algorithm, a set of relatively optimal feedback data is obtained that $b_1 = -0.7756$, $b_2 = 0.4922$, $b_3 = 0.1382$. It's easy to prove that the system is stable. The performance of the filter is: $If = 70.9901dB$, $B_p = 0.6934$, δ_p =1.5085 dB . Obviously, they can all reach the system requirements. It can be seen that the filter has a wide passband bandwidth, a small passband ripple and a high value of improvement factor. Figure 4 shows that the comparison in frequency response between the adaptive recursive MTI filter we design and the non-recursive MTI filter which has no feedback.

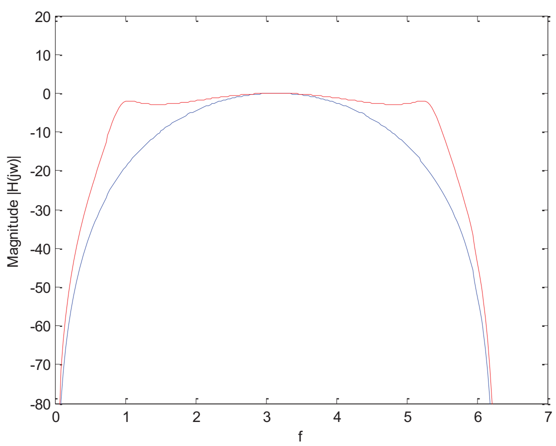

Figure 4. Comparison between recursive MTI filter (the upper, red one) and non-recursive MTI filter (the lower, blue one)

The results of simulation demonstrate that the recursive MTI filter meets all requirements. Compared with the non-recursive MTI filter, it has a wider pass band width and a steeper rising edge. In this case, the signal will be less attenuated after the filter. In addition, the figure 4 shows that the recursive MTI filter has more excellent characteristics of the passband and the transition band than the non-recursive MTI filter.

V. CONCLUSION

This paper presents a kind of effective method for designing adaptive recursive MTI filter. The parameters are divided into two parts: the forward and the feedback parameters. The former is designed the same way as cascaded cancellers. The latter is designed in advance by means of genetic algorithm. The coefficients can be constantly updated with clutter situations. The designed recursive MTI filter not only effectively suppresses clutter according to the clutter change, but also has a steep transition band, and a flat and broad passband. As a result, it is propitious for detecting targets, especially the slow speed targets.

By using the GA, not only the design method is flexible, but also the seeking speed of the feedback parameters is accelerated and the near-global optimum parameters can be found. Sequentially, the recursive MTI filter is easy to be implemented with hardware.

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