An Optimization Method of MIMO Radar Array Based on Genetic Algorithm

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Abstract. Since the traditional radar imaging takes too much time, it is necessary to find new imaging radar which can image fast and conserve resources. MIMO radar has waveform diversity or spatial diversity. So it can realize high resolution snapshot imaging under the same condition. However, the imaging performance of MIMO radar is tightly related to the antenna array design. This paper proposes a MIMO array optimization method based on the genetic algorithm (GA). The GA is used to directly calculate the position of the transceiver element and at meantime the fitness function based on MIMO array design is proposed. Experiments show that this method not only can reduce the number of array elements, but also has certain optimization ability in beam pattern performance.

Introduction

The imaging performance of MIMO radar is tightly related to the antenna array design. In order to improve the imaging performance, the array design should be based on the target and the specific imaging scene. Rabideau expresses the relationship between the transmitter and receiver array elements, signal, aperture length and imaging performance in the paper [1]. Imaging technologies based on sparse array design continue to evolve. Such as Mini-Redundancy Linear Arrays (MRA) [2], Nested Array (NA) [3], Composite Array (CA) [4] and other array are available [5, 6]. MIMO radar is a kind of special array radar. Therefore, many scholars study MIMO radar based on the basis of sparse array [7, 8]. Chen Gang combines the difference set theory with genetic algorithm (GA) to realize the quick array arrangement of MIMO radar [9]. In order to reduce the side lobe level of the pattern and solve the zero trap problems [10], Dong Jian and others proposed a beam optimization method design combining the differential evolution (DE) and particle swarm optimization (PSO) algorithm. Sun designed a sparse nested MIMO array [11]. However, there is a common problem with these methods, which are based on the virtual array elements of MIMO radar. It is easy to design a virtual array that meets the requirements, but the actual transceiver array is not optimal.

This paper proposes a MIMO array design method based on genetic optimization algorithm to directly calculate the position of the transceiver element. According to the characteristics of MIMO radar, the fitness function is designed and the genetic optimization algorithm is used to solve the problem of the traditional exhaustive design method wasting computing resources. The method also has the potential for quadratic optimization and gives a MIMO array with optimal pattern performance.

MIMO Radar Array Design Method

Basic Concepts

Virtual Array

There is a M-transmit-N-receive MIMO radar system, and the transmitted signals are orthogonal to each other. The signals are separated by matched filter to form MN signal channels at the receiving end. The transmitting array steering vector \( \mathbf{v}_T \), the receiving array steering vector \( \mathbf{v}_R \) and the array
steering vector of all channels \( \mathbf{V} \) can be expressed as Eq. 1, Eq.2 and Eq.3. Through them, we can know the relationship among \( \mathbf{V}, \mathbf{V}_T \) and \( \mathbf{V}_R \) which is as shown as Eq. 4.

\[
\mathbf{V}_T = \left[ e^{j\theta_1}, \ldots, e^{-j\theta_M} \right]
\]

(1)

\[
\mathbf{V}_R = \left[ e^{j\theta_1}, \ldots, e^{-j\theta_M} \right]
\]

(2)

\[
\mathbf{V} = \mathbf{V}_T \otimes \mathbf{V}_R
\]

(3)

\[
\otimes \text{ is the Kronecker product. Through space convolution, MN virtual elements can be obtained.}
\]

**Sparse Nested Array**

As shown in Fig. 1, the structure is composed of two uniform linear arrays with different spacing, which are called inner linear array (\( S_{inner} \)) and outer linear array (\( S_{outer} \)). \( S_{inner} \) is composed of \( N_1 \) elements with a mutual interval of \( d_1 \); \( S_{outer} \) is composed of \( N_2 \) elements with a mutual interval of \( d_2 = (N_1+1)d_1 \). Its position can be expressed by Eq. 5, Eq. 6.

\[
S_{inner} = \{ nd_1, n = 1, \ldots, N_1 \}
\]

(5)

\[
S_{outer} = \{ n(N_1 + 1)d_1, n = 1, \ldots, N_2 \}
\]

(6)

Table 1 show the best value of inner and outer elements when the total elements are fixed.

![Figure 1. The structure of Nested array.](image)

| Total number of array elements \( N \) | \( N_1, N_2 \) | Degree of Freedom |
|--------------------------------------|----------------|------------------|
| Odd \( N_1 = (N-1)/2, N_2 = (N+1)/2 \) | \( \left( N^2 - 1 \right)/2 + N \) |
| Even \( N_1 = N_2 = N/2 \) | \( \left( N^2 - 2 \right)/2 + N \) |

**The Optimization Method Based on GA**

It is assumed that the number of elements of the virtual nested array is recorded as \( Q \). The structure of MIMO radar is \( M \)-transmit-\( N \)-receive. However, this optimal condition often does not exist. This problem can be described mathematically by Eq. 7. Where \( \{ x_i \} \) represents the potential of the set \( \{ \mathbf{x}_i \} \), \( x_i (i = 1, \ldots, Q) \) is the element coordinates. And the optimization process is shown in Fig. 3.

\[
\min_{\{x_m\} \mid m=1,2} M + N \quad s.t. \quad \left| \left\{ x_{T,m} \right\} \right| = M, \left| \left\{ x_{R,n} \right\} \right| = N, \left\{ x_{T,m} + x_{R,n} \right\} \supset \left\{ x_{i_1}, \ldots, x_{i_Q} \right\}
\]

(7)

**Encoding:** For a virtual nested array with \( Q \) elements, the number of inner and outer linear array elements is \( N_1 \) and \( N_2 \). \( K \) is the maximum value of element position which should meet the Eq. 8:
\[ K = \left[ N_2 \left( N_1 + 1 \right) \right] \tag{8} \]

\( N_1, N_2 \) are shown in Table 1. The genotype includes the upper and the lower. The upper represents the transmitting array, and the lower represents the receiving array.

**Fitness function:** The individual gene is decomposed into a matrix consisting of a transmitting vector \( x_{iT} \) and a receiving vector \( x_{iR} \). The positional repetition degree \( \text{fitness}(x_i) \) is:

\[
\text{fitness}(x_i) = (\text{len}(x_{iT}) - \text{len}(\text{key}(x_{iT}))) + (\text{len}(x_{iR}) - \text{len}(\text{key}(x_{iR})))
\]

where \( \text{len}() \) is a function for calculating the length of the vector, \( \text{key}() \) performs a non-repetitive element storage operation. Calculate the accumulation probability as shown in Eq. 10, Eq. 11.

\[
f_i = \frac{f(x_i)}{\sum_{i=1}^{I} f(x_i)},\quad i = 1, \cdots, I
\]

\[
c_i = \sum_{j=1}^{i} f_j
\]

\( c_i \) is cumulative probability of each individual,

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**Simulations**

**Simulation 1:** The number of virtual elements \( Q=12, N_1=N_2=6 \). The population size \( \text{popsize}=50 \), the mating probability \( \text{pcrossover}=0.9 \), and the mutation probability \( \text{pmutation}=0.09 \). Fig. 3 shows the structure of the traditional array and the nested array based on GA. Fig. 4 is the antenna beam pattern.

**Simulation 2:** Table 2 is the initial value of the optimization algorithm and the results based on GA. Fig. 5 shows the trends of the fitness function with different virtual array elements.

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**Figure 2. Sparse nested MIMO array design flow chart.**

**Figure 3. MIMO radar transceiver array structure.**
Table 2. Seed collection location and date of the eight study species.

| Number of virtual elements | Actual number of elements | Iteration times | Initial population |
|---------------------------|---------------------------|-----------------|--------------------|
| 12                        | 12                        | 80              | 50                 |
| 20                        | 20                        | 150             | 100                |
| 30                        | 28                        | 300             | 200                |
| 40                        | 39                        | 450             | 280                |

Analysis

According to the comparison of Fig. 3, the GA optimization algorithm can save 1 array element under the 12 virtual arrays. As shown in Fig. 4(c), the virtual array beam formed by the traditional array indicates that the 3dB main lobe width is 2.5° and the PLSR is -13.3dB before the improvement. After the GA algorithm is used, the main lobe width is 2.1° and the PLSR is -10dB. Through the above experiments, the array structure obtained by combining the GA and the nested array can effectively save the elements and improve the azimuth resolution. Table 2 shows that the optimization parameters need to change according to the number of virtual elements. Experiments indicate that when the initial population or the number of iterations is too small, the optimization algorithm will fall into the local optimal situation. In addition, as we can see in Fig. 5, there are several results...
satisfied the optimization conditions. Therefore, the array design results can be further optimized according to the antenna pattern.

Conclusions

This paper proposes a MIMO array optimization method based on GA and the nested array. The GA is used to directly calculate the position of the transceiver element, which solves the problem that wasting computing resources. However, there is more than one result of optimization, and this paper does not discuss the amount of calculation in detail. The subsequent steps can further clarify the degree of optimization of the method in terms of the amount of calculation and the number of elements. In addition, it can be combined with the beam pattern for secondary optimization to design a better performance array structure.

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