

Decomposition Algorithm for Antenna Designs with a Large Scale of Variables and High dimension of objectives

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The antenna is an essential device in modern communication systems, antenna designs are imperative to provide a high-performance option. As the antenna is trending towards multifunction and systematization, antenna designs are often involved with a large scale of optimization variables and high dimensional objectives. A decomposition algorithm based on dynamic random grouping and aggregation trees is proposed to solve the antenna designs with a large scale of variables and objectives. To search the variable space efficiently, variables are divided into several groups, which are checked and updated during the evolutionary process. To enhance the evolutionary pressure in high dimensional objective comparison, the aggregation trees method is used to remove the non-conflict or weak-conflict objectives. A 30-element linear antenna array and a filter antenna are used to test the effectiveness and efficiency of the proposed method. The numerical results demonstrate that the proposed decomposition method can obtain qualified and satisfied options for complex antenna designs with fewer computational costs.

Index Terms—Optimization methods, Antenna array, Design optimization

I. INTRODUCTION

As a fundamental component, the antenna plays an important role in modern communication systems, which is directly impacting performance and reliability. With the trend of systematization and multifunction in the communication demands and the rapid advancement of technology, antenna design has become more and more complex, which often evolves with a large scale of variables and high dimensional objectives that need to be considered synchronously. The huge numbers of decision variables and high dimensional objectives make it difficult to find optimal solutions for antenna designs. Firstly, the vast searching space and the diversity of objective functions make traditional optimization algorithms hard to converge and tend to trap into local optima. Secondly, antenna design often depends on numerical computation, such as finite element analysis (FEA), which is very time-consuming.

To address these challenges, a decomposition algorithm based on dynamic random grouping and an aggregation tree is proposed in this paper. The dynamic random grouping method is used to divide the variable space into sub-domains. The aggregation tree method is adopted to remove the non-conflict or weak-conflict objectives. The antenna design with a large scale of variables and high dimensional objectives can be solved by decomposing the complex optimization problem into a series of simple ones.

II. THE DECOMPOSITION ALGORITHM BASED ON DYNAMIC RANDOM GROUPING AND AGGREGATION TREES

A. Decomposition Framework

To utilize the idea of “divide and conquer”, a decomposition framework is developed, which is shown in Figure 1. As shown in Figure 1, in order to analyze the relationship of objectives precisely, the conflict analysis among the objectives

is implemented in the first step; after the redundant objectives are removed, the variable space is divided.

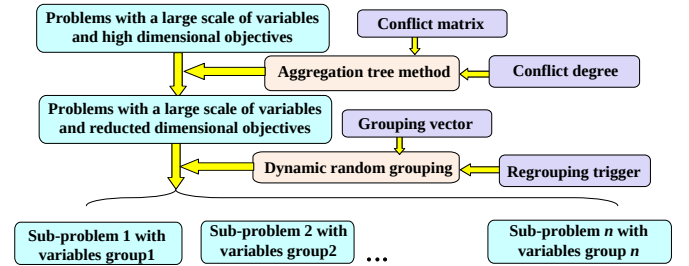


Figure 1 Instruction of decomposition framework

B. Dynamic Random grouping method

To locate the promising area efficiently, variable grouping is used in large-scale-variable optimization problems. Random grouping is that the variables are selected randomly into several groups to build sub-problems, which are easy to manipulate and need no extra computation. A dynamic random grouping method consisting of a group number vector and a regrouping trigger is used. The group number vector provides the desired number of groups. The regrouping trigger determines whether the current grouping is suitable for evolution.

C. Aggregation tree method

The aggregation tree method is designed to compute the conflict degree between objectives and deduct the redundant objectives. The conflict degree between two objectives is calculated based on non-parametric rank conflict[1]:

$$Conflict_{ab}^i = C_{ab}^i / C_{\max}^i \quad (1)$$

$$C_{ab} = \sum_i |X_{ia}' - X_{ib}'| \quad (2)$$

$$X_{ij}' = R_{ij} \quad (3)$$

$$C_{\max} = \sum_{i=1}^n |2i - n - 1| \quad (4)$$

Where $Conflict_{ab}^i$ is the conflict degree between objective

a and b in the i_{th} iteration; C_{ab} is the non-parametric rank conflict between objective a and b ; C_{max} is the maximum conflict.

III. NUMERICAL RESULTS

To test the performance of the proposed method, a series of mathematic test functions and a filtering antenna optimal design are solved.

A. WFG function test

The parameters of the proposed method are set as: variable dimension $Dim=30$, initial population size $N=100$, max number of function evaluations $FE_{max}=20000$, number of objectives $M=5$. To evaluate the algorithms' performance, IGD and HV are used. The proposed decomposition method is compared with MOEA/D[2], MOFWA[3], and NSGAIII[4] by 20 independent runs.

The IGD and HV indicators are given in Table 1. From Table I, it is shown that the proposed method obtain the smallest IGD values on test function WFG1-WFG6 [5], which means the solutions searched by the proposed method are closest to the true solutions. On the aspect of HV values, the proposed method has the best performance in WFG1 and WFG2; and second best in WFG3, WFG5, and WF6.

TABLE I
Comparison of IGD and HV solving WFG1-WFG6

Test Function	Indicator	Proposed Method	MOEAD	MOFWA	NSGAIII
WFG1	IGD	1.1933	2.6714	2.2577	2.6584
	HV	0.3453	0	0.1401	0.0435
WFG2	IGD	0.7133	1.0003	1.1733	3.4462
	HV	0.9234	0.8008	0.6799	0.5158
WFG3	IGD	0.2299	0.4645	2.6891	2.7994
	HV	0.1133	0.0686	0.4346	0
WFG4	IGD	1.9784	3.3174	2.3852	6.1418
	HV	0.2527	0.3469	0.3188	0.1775
WFG5	IGD	2.0529	2.1467	2.3601	3.2961
	HV	0.2094	0.3101	0.2051	0.0657
WFG6	IGD	1.7001	2.1899	2.2867	4.6371
	HV	0.2385	0.3633	0.2183	0.1140

B. Filtering Antenna Optimal Design

The filtering antenna is an antenna that combines the functionality of a filter, which can reflect unwanted out-of-band noise and interfering signals [6]. Here an ultra-wideband (UWB) filtering antenna with the frequency band from 3 to 10 GHz is optimized. The narrowband interfering signals are centered on 3.5GHz, 5.8GHz, and 6.2GHz. The structure of the filtering antenna is given in Figure 2. The mathematical model for the filter antenna optimization is as follows:

$$F_1 = \frac{1}{N_s} \sum_{i=1}^{N_s} S_{11}(i) \quad F_2 = -\frac{1}{N_s} \sum_{i=1}^{N_s} Gain(i) \quad (5)$$

$$\text{s.t. } S_{11}(i) \leq -10\text{dB}, \text{ Gain}(i) \geq 3\text{dB}$$

$$S_{11}(3.5\text{GHz}) > -10\text{dB}, \text{ Gain}(3.5\text{GHz}) < 0\text{dB} \quad (6)$$

$$S_{11}(5.8\text{GHz}) > -10\text{dB}, \text{ Gain}(5.8\text{GHz}) < 0\text{dB}$$

$$S_{11}(6.2\text{GHz}) > -10\text{dB}, \text{ Gain}(6.2\text{GHz}) < 0\text{dB}$$

In this study, 18 parameters shown in Figure 2 are selected as variables of the antenna's optimal design. The parameters of the proposed optimization algorithm are set as: $Dim=18$, $N=50$, $FE_{max}=1000$. Figure 3 presents the simulation results based on the optimized variables, including the S_{11} , $Gain$, $VSWR$, and Z_{re} . From Figure3, it is shown that the proposed algorithm can provide a qualified antenna design candidate.

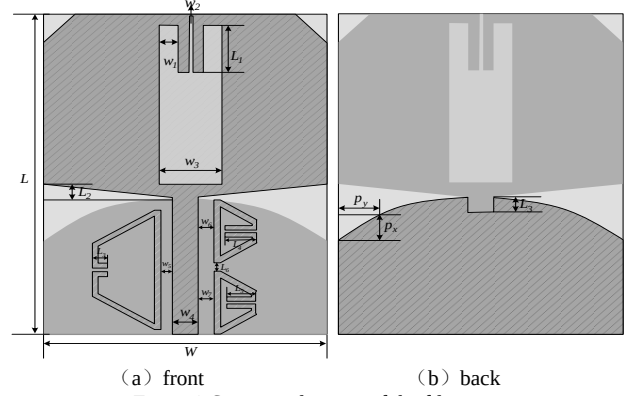


Figure 2 Structure diagram of the filtering antenna

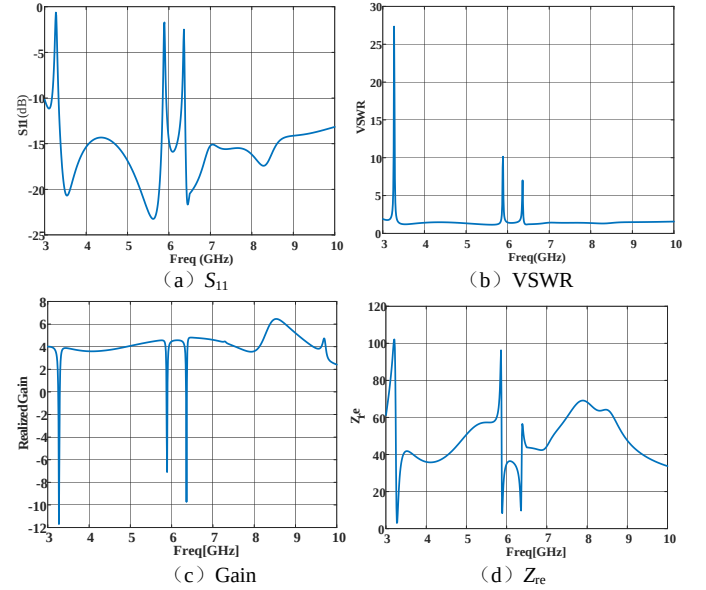


Figure 3 Optimization results of filtering antenna

REFERENCES

- [1] G. Zou, X. Su, S. An, Shilong Xiao, "Incorporating aggregation trees in two-archive algorithm 2 for solving high dimensional multi-objective electromagnetic optimization", International Journal of Applied Electromagnetics and Mechanics, 71, pp. S117-S126, 2023.
- [2] Q. Zhang and H. Li, "MOEA/D: A multi-objective evolutionary algorithm based on decomposition", IEEE Trans. Evolutionary Computation, vol. 11, no. 6, pp. 712-731, 2007.
- [3] Y. Tan, "FWA for multiobjective optimization," in *Fireworks Algorithm*, Springer, Berlin, Heidelberg, pp. 151-172, 2015.
- [4] K. Deb and H. Jain, "An evolutionary many-objective optimization algorithm using reference-point-based nondominated sorting approach, Part I: Solving problems with box constraints", IEEE Trans. Evolutionary Computation, vol. 18, no. 4, pp. 577-601, 2014.
- [5] Huband S, Hingston P, Barone L, et al. "A review of multiobjective test problems and a scalable test problem toolkit", IEEE Trans. Evolutionary Computation, vol.10, no.5, pp. 477-506, 2006.
- [6] J. Deng, S. Hou, L. Zhao, et al., "A reconfigurable filtering antenna with integrated bandpass filters for UWB/WLAN applications", IEEE Trans. Antennas Propag., vol. 66, no. 1, pp. 401-404, 2018.