5 by 5 Microstrip Antenna Array Design by Multiobjective Differential Evolution based on Fuzzy Performance Feedback

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ABSTRACT

Differential evolution is often regarded as one of the most efficient evolutionary algorithms to tackle multiobjective optimization problems. The key to success of any multiobjective evolutionary algorithms (MOEAs) is maintaining a delicate balance between exploration and exploitation throughout the evolution process. In this paper, the authors develop an Improved version of the Fuzzy-based Multiobjective Differential Evolution (IFMDE) that exploits performance metrics, specifically hypervolume, spacing, and maximum spread, to measure the state of the evolution progress. They apply the fuzzy inference rules, derived from domain knowledge, to these metrics in order to dynamically adjust the associated control parameters of a chosen mutation and crossover strategy used in this algorithm. One mutation parameter controls the degree of greedy or exploitation, while another regulates the degree of diversity or exploration of the reproduction phase. On the other hand, crossover rate controls the fraction of trial vector elements inherited from the mutant vectors. In doing so collectively, the authors can appropriately adjust the degree of exploration and exploitation through performance feedback. A 5 by 5 microstrip antenna array design problem is formulated as a three-objective optimization problem. The proposed IFMDE is applied to tackle this problem under real-world complications. Since the objective evaluations of a 5 by 5 microstrip antenna array are computationally very expensive, a radial basis function neural network is trained as a surrogate model for the fitness function approximations. The experimental results demonstrate the ability of IFMDE that it can find not only one, but a set of Pareto optimal solutions, specifically in terms of side lobe level and reflection coefficient. These multiple Pareto-optimal configurations can then be chosen from by a decision maker given dynamic operating environments, constraints and uncertainties.

KEYWORDS
Fuzzy Logic, Hypervolume, Maximum Spread, Multiobjective Differential Evolution, Performance Metrics, Spacing

INTRODUCTION

Antenna design which focuses on converting electric power into radio waves while satisfying stringent, conflicting, and often unusual design specifications has been regarded as one of the most challenging engineering problems. The antenna engineers design the antenna's electrical and geometrical configurations in order to achieve the optimal performance. The design goals can be specified as maximizing antenna gain while minimizing side lobe level and reflection coefficient. They are usually conflicting objectives to be achieved simultaneously. As a result, the antenna design problems is considered a multiobjective optimization problem (MOP) by nature.

Microstrip antennas are widely used in various wireless communication systems such as mobile communications, radar, missiles, aircraft, satellite communication systems, etc. They are preferred
over the other types of antennas due to their low-profile, light weight, conformal ability, ease and low cost of manufacturing, and readily to be integrated within the microwave integrated circuits (Pozar & Schaubert, 1995; Garg, 2001; Waterhouse, 2003). There exists various utilities not only for single element microstrip antennas but most recently wide-ranging applications in microstrip antenna arrays. Microstrip antenna arrays provide higher directivity and gain than the single element antennas and are very versatile (Balanis, 2005). In this paper, a 5x5 microstrip antenna array synthesis for a 12.5 GHz broadcasting satellite service is formulated as a three-objective optimization problem as a case study with sufficient complexity, yet computationally manageable. In addition, for traditional antenna design field, there exist no such a general antenna synthesis methodology. Existing antenna design approaches have been developed but tailored for specific antenna type (Stutzman & Thiele, 2013). Therefore, the need to call for a universal design procedure, even heuristic in nature, is critical to advance the utilities of microstrip antenna arrays.

One of the most powerful heuristic optimization algorithms is Differential Evolution (DE). DE was proposed by Storn and Price in 1995 as a novel evolutionary algorithm (EA) (Storn & Price, 1995; Storn, 1996; Storn & Price, 1997). It is a stochastic, population-based search approach for optimization over a continuous space (Abbass, 2002). DE can efficiently handle the mixed-type variables, various constraints, multimodality and also MOPs. Therefore, we propose in this paper an Improved version of the Fuzzy-based Multiobjective Differential Evolution (FMDE) (Jariyatantiwait & Yen, 2014), in short for IFMDE, in order to exploit the feature capability of the proposed IFMDE under real-world complications. In addition, due to the expensive computations in objective evaluations, a radial basis function neural network is trained as a surrogate model for objective function evaluations, given a limited number of data samples possibly made available.

The mutation strategy and its control parameters, specifically scaling factor ($F$), crossover rate ($CR$), and population size ($NP$), play critical roles in the performance of a given differential evolution based optimization algorithm. Choosing an appropriate mutation operator and its associated parameter values for a particular problem at hand is often a problem dependent, time-consuming, and trial-and-error, dynamic process. To address the challenge, several references (Abbass, 2002; Huang et al., 2007; Zamuda et al., 2007; Zielinski & Laur, 2007; Zhang & Sanderson, 2008; Huang et al., 2009) proposed adaptive control strategies to adjust the parameter setting of DE during the search process. If we know the state of the evolution process, we may decide whether we should emphasize on exploration or exploitation, and choose suitable parameter values or the mutation strategies accordingly. One possible way that we can estimate the state of the evolving process is utilizing the performance metrics. However, most of the performance metrics available are evaluated at the end of the evolution in order to assess the quality of the obtained nondominated front and the process requires a complete knowledge of the true Pareto front. For instance, calculating generational distance demands a good sample of the true Pareto front. In addition, the quality of the population can be portrayed through three quantitative properties of the obtained nondominated front (Zitzler et al., 2000), i.e., the convergence, uniform distribution, and extensiveness. Even though there are some proposed running performance metrics (Deb & Jain, 2002) to measure the quality of the current population on the fly, there are very few options to allow us to measure the three qualities of the population. In this study, we designate three running metrics, namely hypervolume, spacing, and maximum spread to quantify the three qualitative properties of the obtained nondominated solutions.

However, the diversity maintenance used in FMDE is found ineffective because we have a constant crossover rate throughout the search process. In this paper, the proposed Improved FMDE (i.e., IFMDE) dynamically adjusts the associated control parameters of mutation strategy in concurrent with the crossover rate in order to improve the diversity control of the population. IFMDE exploits hypervolume, spacing, and maximum spread as the input to the fuzzy inference rules. The outputs of fuzzy rules are the greedy factor, the diversity factor for the mutation scheme, and the crossover rate. These parameters are adaptively adjusted at every generation in order to promptly balance the
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