Particle Swarm Optimization as Applied to Electromagnetic Design Problems

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ABSTRACT

Particle swarm optimization (PSO) is a swarm intelligence algorithm inspired by the social behavior of birds flocking and fish schooling. Numerous PSO variants have been proposed in the literature for addressing different problem types. In this article, the authors apply different PSO variants to common design problems in electromagnetics. They apply the Inertia Weight PSO (IWPSO), the Constriction Factor PSO (CFPSO), and the Comprehensive Learning Particle Swarm Optimization (CLPSO) algorithms to real-valued optimization problems, i.e. microwave absorber design, and linear array synthesis. Moreover, the authors use discrete PSO optimizers such as the binary PSO (binPSO) and the Boolean PSO with a velocity mutation (BPSO-vm) in order to solve discrete-valued optimization problems, i.e. patch antenna design. Additionally, the authors apply and compare binPSO with different transfer functions to thinning array design problems. In the case of a multi-objective optimization problem, they apply two multi-objective PSO variants to dual-band base station antenna optimization for mobile communications. Namely, these are the Multi-Objective PSO (MOPSO) and the Multi-Objective PSO with Fitness Sharing (MOPSO-fs) algorithms. Finally, the authors conclude the paper by providing a discussion on future trends and the conclusion.

KEYWORDS
Electromagnetics, Inertia Weight PSO, Particle Swarm Optimization, Social Behavior

INTRODUCTION

In the past decade, several swarm intelligence (SI) algorithms that mimic the social behavior of swarms of birds, insects and other animals emerged. Among others, Particle Swarm Optimization (PSO) is a popular SI algorithm, which is based on the intelligence and movement of swarms of birds and resembles their behavior (Kennedy & Eberhart, 1995).

PSO and other evolutionary computation techniques such as Genetic Algorithms (GAs) exhibit several similarities. The main difference between PSO and GAs is the fact that PSO does not have any evolution operators like crossover and mutation. Moreover, PSO compared to GAs requires the adjustment of lesser parameters. Furthermore, PSO is an easy to implement algorithm in just a few lines of code in any programming language. PSO can also be regarded as computationally more efficient than a GA with the same population size.

Several PSO applications exist in the literature in different engineering disciplines: function optimization, artificial neural network training, fuzzy system control and other areas where GAs are also applied. PSO algorithms are very popular for solving problems in electromagnetics, (Baskar,
Alphones, Suganthan, & Liang, 2005; Deligkarakis et al., 2009; Goudos, Moysiadou, Samaras, Siakavara, & Sahalos, 2010; Goudos, Rekanos, & Sahalos, 2008; Goudos & Sahalos, 2006; Goudos, Zaharlis, Kamitsak, Rekanos, & Hilas, 2009; Khodier & Christodoulou, 2005; Robinson & Rahmat-Samii, 2004; Zaharlis, 2008; Zaharlis, Kamitsak, Lazaridis, Papastergiou, & Gallion, 2007).

There are several different PSO algorithms in the literature. Among the common algorithms are the classical Inertia Weight PSO (IWPSO) and the Constriction Factor PSO (CFPSO) (Clerc, 1999). A PSO variant that speeds up convergence and improves PSO performance especially on complex multimodal problems is proposed in (Liang, Qin, Suganthan, & Baskar, 2006). This is called the Comprehensive Learning Particle Swarm Optimizer (CLPSO) and utilizes a new learning strategy. The main advantage of CLPSO algorithm is that can converge faster than the original PSO. CLPSO has been applied successfully to Yagi-Uda antenna design by Baskar et al. (2005) and to linear array synthesis by Goudos et al. (2010).

The above algorithms are inherently used only for real-valued problems but can easily expand to discrete-valued problems. This can be made using a mapping of the real values of the particles positions to binary values by means of a transfer function. This simple modification of the real-valued PSO called binary PSO (binPSO) has been presented by Kennedy & Eberhart (1997). The transfer function of the original binPSO is an S-shape function. The application and the performance evaluation of different S-shaped and V-shaped transfer functions to binPSO is studied in a recent paper (Mirjalili & Lewis, 2013). Moreover, in (Marandi, Afshinmanesh, Shahabadi, & Bahrami, 2006) another discrete valued PSO called the Boolean PSO is introduced and applied to dual-band planar antenna design. The Boolean PSO is based on the idea of using exclusively Boolean update expressions in the binary space. An extension to Boolean PSO, that improves the algorithm performance, is the Boolean PSO with velocity mutation (BPSO-vm) which has been applied successfully to patch antenna design (Deligkarakis et al., 2009).

PSO has also been modified for multi-objective problems, among others multi-objective extensions of PSO include the Multi-Objective Particle Swarm Optimization (MOPSO) (Coello Coelho, Pulido, & Lechuga, 2004) and the Multi-Objective Particle Swarm Optimization with fitness sharing (MOPSO-fs) (Salazar-Lechuga & Rowe, 2005). The above algorithms have also been used in antenna and microwave design problems (Goudos & Sahalos, 2006; Goudos et al., 2009).

In this paper, we briefly describe the aforementioned algorithms and present their application to antenna and microwave design problems. Within this context, we present results from design cases using the IWPSO, CFPSO, CLPSO, binPSO, BPSO-vm and the multi-objective variants MOPSO and MOPSO-fs. The examples comprise the design of high-absorption planar multilayer coatings, the synthesis of unequally spaced linear arrays with sidelobe level (SLL) suppression under mainlobe beamwidth and null control constraints, the synthesis of thinned linear arrays, the design of thinned planar microstrip arrays under constraints of impedance matching, low SLL and null control, and finally the optimization of dual-band base station antennas for wireless networks. We compare our results with optimization methods found in the literature and thus validate the efficacy of PSO. We complete study with a brief discussion of future directions and perspectives in the area.

This paper is subdivided into four sections. First, we present the different PSO algorithms. In the next Section, we describe the design cases and present the numerical results. An outline of future research directions is provided in the following Section while in the “Conclusion” Section we conclude the paper and discuss the advantages of using a PSO-based approach in the design and optimization of microwave systems and antennas.

**BACKGROUND**

Introductory and tutorial papers that introduce the application of the PSO for antenna design are given in (Jin & Rahmat-Samii, 2007; Robinson & Rahmat-Samii, 2004). Additionally, the problem of sidelobe suppression of linear arrays using the PSO has been addressed in (Khodier & Christodoulou, 2004; Papastergiou & Deligkarakis, 2009; Lewis, Afshinmanesh, & Afshinmanesh, 2009; Rekanos, Afshinmanesh, & Deligkarakis, 2009; Robinson & Rahmat-Samii, 2004; Zenim & Deligkarakis, 2009).
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