

An Efficient Hybrid of Evolutionary Programming and Particle Swarm Optimization for Mixed-Parameter Electromagnetic Design Problems

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The application of evolutionary and multi-agent stochastic optimization techniques, such as Evolutionary Programming (EP), Genetic Algorithms (GAs), Particle Swarm Optimization (PSO), and Covariance Matrix Evolution Strategy (CMA-ES), to electromagnetic and antenna design has demonstrated the ability of these probabilistic methods to yield robust, globally optimized solutions for high-frequency design problems. Such problems are often intractable using traditional gradient-based local-search optimization methods. A comparative study of various EP, GA, and PSO variations for antenna design problems revealed that EP consistently achieves the best overall performance among these algorithms. While PSO occasionally produces a few exceptionally high-quality solutions that rival or surpass those of EP, the majority of its solutions across multiple trials are relatively poor compared to other algorithms [H. Huang, A. Hoorfar and S. Lakhani, "A Comparative Study of Evolutionary Programming, Genetic Algorithms and Particle Swarm Optimization in Antenna Design", IEEE AP-S Symposium, 2007.]. This observation raises the question of whether a judicious hybridization of these algorithms could result in a new algorithm with faster convergence. Addressing this question, a hybrid algorithm combining EP with Gaussian mutation and PSO was shown to outperform both standalone EP and PSO in many antenna design optimization problems [A. Hoorfar and S. Lakhani, "Faster Antenna Optimization Using a Hybrid EP-PSO Algorithm," IEEE AP-S Symposium, 2009].

In this work, we extend the hybridization of Evolutionary Programming (EP) and Particle Swarm Optimization (PSO) to address mixed-parameter optimization problems, which commonly arise in many practical electromagnetic design scenarios. For instance, in the design of multilayer dielectric filters, the layer thicknesses are continuous parameters, while the permittivity values, selected from a pool of commercially available materials, represent discrete optimization parameters. Other examples, include pixilated antenna and metasurface designs, and joint direction of arrival and mutual coupling estimation in sparse arrays [E. Beers, A. Hoorfar and M. Amin, "Joint Estimation of Mutual Coupling and Direction of Arrival for 2D Sparse Arrays using CMA-ES," IEEE AP-S Symposium, 2023].

The proposed mixed-parameter algorithm integrates PSO's swarm dynamics into the standard self-adaptive EP framework for optimizing continuous parameters. For discrete (binary) parameters, we introduce a self-adaptive discrete mutation mechanism based on a Poisson probability distribution. The process flow of the proposed technique is illustrated in Figure 1. Additionally, we explore the use of a hybrid Gaussian-Cauchy mutation operator to further enhance the efficiency and versatility of the algorithm. This enhancement enables the effective optimization of a diverse range of antenna and microwave design problems. Numerical results for various continuous and mixed-parameter optimization scenarios will be presented to demonstrate the technique's effectiveness.

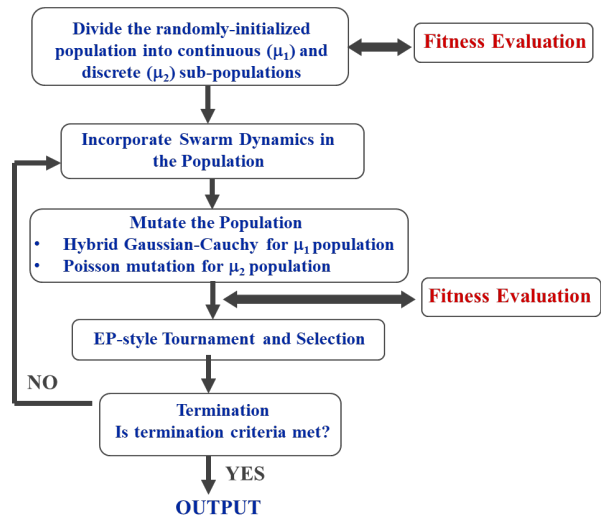


Figure 1. Flow chart of mixed-parameter EP-PSO algorithm