Chapter 3
Swarm Intelligence for Electromagnetic Problem Solving

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ABSTRACT
The chapter will describe the potential of the swarm intelligence and in particular quantum PSO-based algorithm, to solve complicated electromagnetic problems. This task is accomplished through addressing the design and analysis challenges of some key real-world problems. A detailed definition of the conventional PSO and its quantum-inspired version are presented and compared in terms of accuracy and computational burden. Some theoretical discussions concerning the convergence issues and a sensitivity analysis on the parameters influencing the stochastic process are reported.

INTRODUCTION
Optimization is an important paradigm widely used in various fields, including engineering, economics, management, physical sciences, social sciences, etc.. The goal of the optimization is the identification of the global maximum or minimum of a fitness function. Indeed, finding all optimal points of an objective function is helpful to select a robust design where different constraints and performance criteria are taken into account simultaneously.

The designers of microwave and antenna systems are constantly challenged in searching optimum solutions for a variety of electromagnetic problems of increasing complexity. This is typically an arduous subject to solve since it requires the evaluation of electromagnetic fields in three dimensions, involves a large number of parameters and complex constraints. Furthermore, the computational domain could contain non-differentiable and discontinuous regions (Mescia et al., 2016; Bia et al., 2015; Ciuprina et

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al., 2002; Robinson & Rahmat-Samii, 2004). These optimization problems are in many cases non-linear and more difficult to solve than the linear ones, especially when the problem has many local optimal solutions in the feasible region.

As the availability of unprecedented computational resources has become common, numerically based electromagnetic methodologies useful to the design of antenna and microwave devices as well as to the understanding of the underlying physics have turned to be significantly advantageous. However, the increasing complexity of antenna and microwave systems makes the computation of three-dimensional electromagnetic field distributions still time consuming and cumbersome. This results in a continuously growing demand for better speed and efficiency of computational approaches. Moreover, contrary to the design of electrical circuits, the development of electromagnetic systems requires special attention in the modeling of coupling processes between design elements. As a consequence, a direct application of brute-force computational techniques is often replaced by the state-of-the-art optimization procedures.

The computer-based optimization techniques can be classified into deterministic and stochastic methods. Contrary to deterministic search techniques, stochastic ones are potentially able to find the global optima of the problem regardless the initial points of the search procedure. Therefore, the so-called metaheuristics algorithms have become increasingly popular because of their potential in solving large-scale problems efficiently in a way that is impossible by using deterministic algorithms.

Swarm intelligence offers insight into metaheuristics. This is quite a general concept based on the interaction and information exchange between multiple agents. In particular, a swarm intelligence system consists of a population with members having characteristic behaviors and interacting locally with each other within their environment following simple rules. Such simple systems can show complex and self-organized behavior. Moreover, even if a dictating centralized mechanism is not embedded, said interactions yield a collective intelligence resulting in a more organized and directive behavior than that of a stand-alone individual.

The resulting metaheuristic algorithms are gaining popularity within the electromagnetic research community and among electromagnetic engineers as design tools and problem solvers thanks to their capability to efficiently find global optima without being trapped in local extrema, and the possibility to address nonlinear and discontinuous problems possibly characterized by great numbers of variables (Fornarelli & Mescia, 2013; Jin & Rahmat-Samii, 2007). Metaheuristic algorithms tend to be flexible, efficient and highly adaptable, as well as easy to implement. They also allow dealing with very complex fitness functions since the computation of derivatives is not needed during the optimization procedure. Furthermore, contrary to more traditional searching methods, their convergence do not strongly depend on the starting point. Therefore, the high efficiency of these algorithms make them an invaluable tool to optimize non-differentiable cost functions in complex multimodal search spaces. However, due to the strong stochastic behavior, these algorithms need a lot of iterations to get a meaningful result (Aboul Ella Hassanien & Eid Emary, 2015).

Since descriptors and number of unknowns to be determined is different in each optimization problem, a variety of swarm intelligence-based optimization algorithms have been developed. They include particle swarm optimization, ant colony optimization, cuckoo search, firefly algorithm, bat algorithm, artificial fish swarm algorithm, flower pollination algorithm, artificial bee colony, wolf search algorithm, gray wolf optimization (Aboul Ella Hassanien & Eid Emary, 2015). As a result, the choice of a proper algorithm is a key issue especially considering that a general rule for this choice does not exist, yet. Typical features helping to a fair decision in this matter regard good convergence properties, ease of use,
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