

Multiobjective Quantum Manta Ray Foraging Optimization Applied to Electromagnetic Optimization

Leandro dos Santos Coelho¹, Yan Lieven Souza Lúcio¹, Luiza Scapinello Aquino¹, and Viviana Cocco Mariani²

¹Graduate Program in Electrical Engineering (PPGEE), Federal University of Parana (UFPR), Curitiba, PR, Brazil

²Graduate Program in Mechanical Engineering (PGMec), Federal University of Parana (UFPR), Curitiba, PR, Brazil

Manta Ray Foraging Optimization (MRFO) is a nature-inspired metaheuristic that mimics manta ray behavior while foraging in the marine environment proposed originally for single-objective optimization. It aims to solve complex optimization problems by replicating how manta rays find and grab their prey. In this paper, the numerical results are reported to validate a novel multi-objective optimization algorithm inspired by MRFO (MOMRFO) to solve the Testing Electromagnetic Analysis Method (TEAM) workshop benchmark problem 25. Simulation results demonstrate the validity of the proposed MOMRFO to find nondominated solutions that represent good trade-offs among the objectives in the evaluated problem. Furthermore, the results demonstrate that MOMRFO offers superior performance in terms of convergence speed, solution diversity, and overall optimization quality, making it a promising tool for solving complex electromagnetic problems.

Index Terms — Optimization, finite element method, multiobjective optimization, swarm intelligence, quantum computing.

I. INTRODUCTION

PROBLEMS in computational electromagnetics request many times the handling of multiple criteria and can be indicated as multiobjective optimization problems (MOPs); examples can be found in [1], [2]. Traditional optimization of mathematical programming often struggles to handle the multi-objective nature of these problems, where trade-offs between conflicting objectives must be carefully balanced. On the other hand, metaheuristics approaches are becoming more prevalent in MOPs to address multiobjective problems. Over the past twenty years, literature has promoted many algorithms for tackling broad multiobjective optimization challenges based on evolutionary optimization [3] and swarm intelligence principles [4].

Based on the efficient foraging behavior of manta rays, Zhao *et al.* [5] proposed a single objective approach termed Manta Ray Foraging Optimization (MRFO). It is a bio-inspired swarm intelligence-based approach inspired by the intelligence behavior of manta rays, mimicking the three foraging strategies the chain, the cyclone, and the somersault hunting of one of the largest known marine creatures. MRFO's cyclone foraging strategy allows it to explore the global search space effectively, reducing the risk of getting trapped in local optima.

MRFO, with its exploration-exploitation equilibrium and adaptive foraging strategies, provides a viable solution to electromagnetic optimization challenges. In this paper, we propose a novel multi-objective optimization algorithm (MOMRFO) that incorporates nondominated rank and a quantum mechanics-based operator inspired by [6], exploiting the natural strategies used by these marine organisms to optimize their hunt for food. The proposed MOMRFO has been evaluated for the optimization of Testing Electromagnetic Analysis Method (TEAM) workshop problem 25 [8].

The rest of this digest is organized as follows: In Section II, the concepts of TEAM workshop problem 25 are briefly

addressed. Section III contains an overview of the MOMRFO, and it summarizes the results achieved. Finally, Section IV provides final remarks.

II. TEAM WORKSHOP PROBLEM 25

Problem 25 from the TEAM workshop was conducted in [7]. It is a benchmark problem designed to evaluate the accuracy and efficiency of computational methods used in electromagnetic field analysis using three objective functions to be minimized. They were defined along the line e-f of the magnetizer in Fig. 1. The first is f_1 , which indicates the global homogeneity of the induction along this line; the second is f_2 , which is a local error that recognizes the maximum relative deviation on the amplitude from the chosen induction along the line e-f; and finally, f_3 detects the maximum angular deviation along the line e-f.

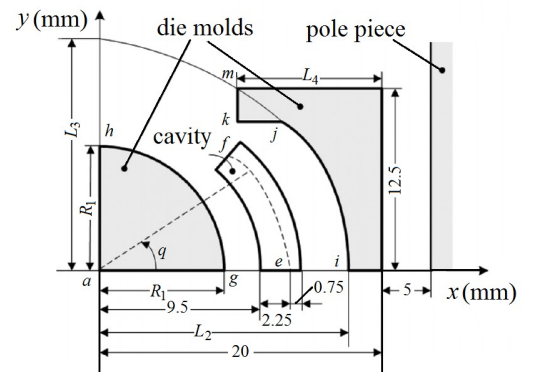


Fig. 1. Representation of the TEAM workshop problem 25.

III. THE PROPOSED MOMRFO APPROACH

The proposed MOMRFO integrates a nondominated sorting strategy with the crowding distance mechanism, originally introduced in the Non-dominated Sorting Genetic Algorithm II (NSGA-II) [8], to effectively handle multi-objective optimization problems. The nondominated sorting strategy ranks solutions based on Pareto dominance, ensuring that the

algorithm prioritizes non-dominated solutions across multiple objectives. The crowding distance metric is employed to maintain diversity within the population by promoting a uniform distribution of solutions along the Pareto front. This combination allows MOMRFO to balance convergence and diversity, which are critical for achieving high-quality Pareto-optimal solutions.

In addition to these mechanisms, MOMRFO incorporates a quantum-inspired operator, which is derived from principles of quantum mechanics. Specifically, the quantum operator is modeled using the quantum delta potential well concept, a theoretical framework that describes the behavior of particles in a confined quantum system. This operator is inspired by quantum particle swarm optimization approaches, as demonstrated in previous studies [9],[10]. The quantum delta potential well model enables particles (or solutions) to exhibit quantum behaviors, such as tunneling and superposition, which enhance the exploration capabilities of the algorithm.

The integration of the quantum operator into MOMRFO is particularly advantageous for complex multi-objective problems, where traditional optimization algorithms may struggle to maintain a balance between exploration and exploitation. The quantum-inspired mechanism allows the algorithm to dynamically adjust the search behavior of individuals in the population, ensuring a robust and efficient optimization process. This innovative combination of classical multi-objective optimization techniques with quantum-inspired operators positions MOMRFO as a tool for solving challenging real-world optimization problems.

The MOMRFO was implemented in MATLAB (MathWorks) computational environment, adopting the parameters: number of independent runs is 50, stopping criterion of 6,000 evaluations of the objective functions, somersault factor equal to 2, and standard weight coefficients as defined in [6] for the chain foraging and cyclone foraging phases. The convergence and diversity of solutions in the objective space results presented in Table I show that the MOMRFO obtained a Pareto front (see Fig. 2) with high coverage and better than NSGA-II [8] in terms of hypervolume results. The best results in Table I in bold indicate that MOMRFO not only yields higher quality solutions on average but also demonstrates superior consistency and reliability when compared to the well-established NSGA-II. Fig. 2 shows that the MOMRFO presents a well-distributed Pareto front.

IV. CONCLUSION

In this digest, a MOMRFO was proposed to solve the TEAM workshop problem 25. The results showed that the algorithm can approximate Pareto optimal solutions with high convergence and coverage. Moreover, MOMRFO seems to be promising in terms of spacing, convergence, and coverage.

In our future work, we will seek to further improve the distribution in objective space in MOMRFO design and compare the results with other multiobjective optimizers based on metaheuristics.

TABLE I
MOMRFO'S PERFORMANCE AGAINST NSGA-II BASED ON HYPERVOLUME

Hypervolume	NSGA-II	MOMRFO
Minimum	6.56×10^{-1}	9.97×10^{-1}
Average	9.61×10^{-1}	9.94×10^{-1}
Median	9.95×10^{-1}	9.91×10^{-1}
Maximum	9.94×10^{-1}	9.93×10^{-1}
Standard deviation	9.21×10^{-2}	1.12×10^{-4}

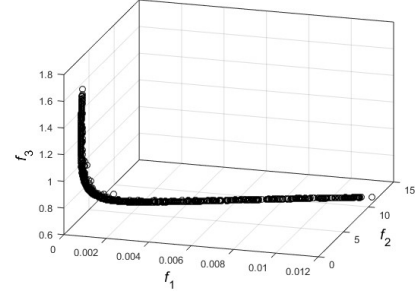


Fig. 2. Pareto set with non-dominated solutions using MOMRFO for 50 runs.

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