A Modified Imperialist Competitive Algorithm for Optimization in Electromagnetics

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Abstract — Recently, a new kind of evolutionary algorithm called Imperialist Competitive Algorithm (ICA) was proposed. ICA is based on a form of competition where the populations are represented by countries divided among imperialists and colonies. In this paper, a modified ICA (MICA) approach is introduced during the search for better solutions. This paper uses a brushless direct current (DC) wheel motor benchmark problem to investigate the performance of the classical ICA and the proposed MICA. Results are shown to be competitive with those of other well-established stochastic optimization methods.

I. INTRODUCTION

Metaheuristics are recognized as powerful methods for the solution of difficult optimization problems related to the design of electromagnetic devices. Among such algorithms, the Imperialist Competitive Algorithm (ICA) was recently introduced in [1] and is a global optimization technique based on the analogy of the action of imperialists in their attempt to conquer colonies. ICA implements the computer simulation of human social evolution in the same spirit with which Genetic Algorithms implement the computer simulation of the biological evolution of species.

Like other population-based algorithms, ICA starts with a random generated population of so-called countries (which are the counterpart of Chromosomes in Genetic Algorithms and Particles in Particle Swarm Optimization). These countries are divided between imperialists, which are the best andidate solutions, and colonies, which are the remaining countries. The main action that leads the search for better solutions in the ICA is the colonies movement towards the imperialists. This mechanism is such that countries tend to converge to certain spots in the search space where the best solution founded so far are located.

In this paper, a modified and improved ICA (MICA) approach is used to solve the brushless direct current (DC) wheel motor benchmark problem described in [2]. Besides, its performance is compared with that of other metaheuristics presented in the recent literature.

II. FUNDAMENTALS OF ICA AND MICA

ICA uses imperialism and imperialistic competition process as a source of inspiration. In this scenario the optimization search space represents the space of socio-political characteristics. ICA starts with an initial population consisting of so-called countries. These countries are divided in two groups. The ones with the best objective function values will be selected to be the so-called imperialists, whereas the remaining ones will be their colonies. All the colonies will initially be shared among the imperialists according to each imperialist's powers. The more powerful an imperialist is the more colonies he will possess. An imperialist together with his colonies forms a so-called Empire.

One characteristic of the imperialism is that in the course of time colonies will starts to change their culture to be more like the culture of their imperialist. This process is implemented in ICA by moving the colonies towards their imperialist and is called Assimilation.

Another possible mechanism of human social evolution is that of Revolution in which sudden random changes take place. Due to both Assimilation and Revolution there is the possibility for a colony to become more powerful than his imperialist, and in this case, the colony will take over the Empire thus becoming the imperialist and the previous imperialist will become a colony.

The competition between different Empires is governed by the fact that the most powerful empires tend to increase their power, while the weakest ones tends to collapse. In the computer simulation, based on their power, all the empires have a chance to take control of one or more of the colonies of the weakest empire. The combination of all these mechanisms will make the algorithm converge into a single empire, in which the imperialist and the colonies will have the same culture.

The proposed MICA uses uniform random distribution to generate the assimilation coefficient, while the revolution rate and step size decrease automatically during iteration.

A detailed description of both ICA and MICA will be given in the extended version of the paper.

III. BRUSHLESS DC WHEEL MOTOR BENCHMARK

A brushless DC wheel motor benchmark was presented in [2] and several optimization results obtained with various algorithms are available in literature. Furthermore, the code for computing the objective function is publicly available [3], thus making the comparison independent of differences in the calculation of the objective function. These features make it ideal for comparing the performances of different techniques.

The problem is characterized by five continuous design variables, which are reported in Table I together with their respective range, and the efficiency η of the motor is to be maximized (which is equivalent to minimizing the motor losses). Furthermore, the problem is subject to six inequality constraints that are related to technological and operational considerations regarding the specific wheel motor.

Constraints are handled by a penalty method by the ICA and MICA approaches.

TABLE I
OPTIMIZATION VARIABLES AND RANGE

Variable	Meaning	Minimum value	Maximum value
D_s [m]	Bore (stator) diameter	0.15	0.33
B_e [T]	Air gap induction	0.50	0.76
δ [A/m^2]	Conductor current density	2.0E6	5.0E6
B_d [T]	Teeth magnetic induction	0.9	1.8
B_{cs} [T]	Stator back iron induction	0.6	1.6

IV. OPTIMIZATION RESULTS

The parameters of both ICA and MICA have been set with number of countries equal to 20. The number of initial imperialists is set to 5 and the stopping criterion was 40 decades (800 objective function evaluations in each run).

Table II shows the results obtained by ICA and MICA results over 30 independent runs. Comparisons with other stochastic techniques are possible for this benchmark. Table III shows a comparison with available results for Sequential Quadratic Programming (SQP) [4],[5], a Genetic Algorithm (GA) [5], Ant Colony Optimization (ACO) [6], and Particle Swarm Optimization (PSO) [6].

In terms of the variables corresponding to the optimal motor configuration, the results are detailed in Table IV. It can be noted that both ICA and MICA were able to reach the same solution found by SQP and ACO, which is most probably the global optimum of the problem, on their best run. However, while the standard ICA did not reach very good results on average and had a rather disappointing worst-case behaviour, MICA obtained very good average results and also hade a very positive worst-case optimum.

It should also be noted that results obtained with ICA and MICA have used far less objective function evaluations than other stochastic algorithms of Table III.

TABLE II
SIMULATION RESULTS OF η IN 30 RUNS

Method	η in %			
	Maximum (Best)	Mean	Minimum (Worst)	Standard Deviation
ICA	95.30	88.71	46.84	0.83
MICA	**95.32**	**95.18**	94.68	0.99

TABLE III
RESULTS OF OPTIMIZATION USING DIFFERENT OPTIMIZATION METHODS

Method	η (%)	Evaluations of η
SQP	95.32	90
GA	95.31	3380
GA & SQP	95.31	1644
ACO	95.32	1200
PSO	95.32	1600
ICA	95.31	800
MICA	95.32	800

V. CONCLUSION

In this paper the performance of the standard ICA and an improved version of the same algorithm (MICA) are tested on a challenging electromagnetic optimization problem. Both algorithms appear to be competitive in terms of the best optimum and MICA also shows a very good average and worst-case behaviour with respect to other well-established optimization techniques. Further benchmarking on other common electromagnetic problems is currently under way and will be presented in the extended version of the paper together with a detailed description of the implementation of the algorithm.

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TABLE IV
COMPARISON OF RESULTS USING DIFFERENT OPTIMIZATION METHODS

Optimization Method	D_s	B_e	δ	B_d	B_{cs}	η	M_{tot}	I_{max}	D_{int}	D_{ext}	T_a
	mm	T	A/mm^2	T	T	%	kg	A	Mm	mm	ºC
SQP [4]	201.2	0.6481	2.0437	1.8	0.8959	95.32	15	125	76	238.9	95.35
GA [5]	201.5	0.6480	2.0602	1.799	0.8817	95.31	15	125	76.9	239.2	95.21
GA & SQP [5]	201.2	0.6481	2.0615	1.8	0.8700	95.31	15	125	76	238.9	95.31
ACO [6]	201.2	0.6481	2.0437	1.8	0.8959	95.32	15	125	76	238.9	95.35
PSO [6]	201.1	0.6476	2.0417	1.8	0.9298	95.32	15	125	79.2	239.8	94.98
MICA	201.2	0.6481	2.0437	1.8	0.8959	95.32	15	125	76	238.9	95.35