

# Biogeography-inspired multiobjective optimization and MEMS design

P. Di Barba<sup>1</sup>, M.E.Mognaschi<sup>1</sup>, A. Savini<sup>1</sup>, and S. Wiak<sup>2</sup>

<sup>1</sup>Department of Electrical, Computer and Biomedical Engineering, University of Pavia, 27100 Pavia, Italy  
{paolo.dibarba, eve.mognaschi, savini}@unipv.it

<sup>2</sup>Inst. of Mechatronics and Information Systems, Łódź University of Technology, ul. Stefanowskiego 18/22, 90-924 Łódź, Poland  
slawomir.wiak@p.lodz.pl

The paper proposes a new version of the biogeography-based optimization algorithm in order to take into account multiple objectives: in fact, by exploiting non-dominated sorting of habitats, it is possible to approximate Pareto-optimal solutions in the objective space. The optimal shape design of an electrostatic micromotor, which is a benchmark in MEMS design, is considered as the case study.

**Index Terms**—Biogeography-inspired optimization, Pareto optimality, MEMS, electrostatic field, finite-element analysis.

## I. INTRODUCTION

EVOLUTIONARY ALGORITHMS are broadly used to optimize the design of electromagnetic devices. In particular, NSGA-II is a popular and well-assessed genetic algorithm for general-purpose multiobjective optimization used in different fields to find Pareto front. Alternatively, optimization algorithms based on a migration strategy have been developed *e.g.* under the frame of parallel computing: accordingly, migration is referred to an exchange of individuals between islands that evolve autonomously [1], [2]. In turn, “island” paradigms mimic the phenomenon of natural populations evolving without exchange with the external environment, such as those that might occur within small islands with limited migration.

In the paper, a modification of a standard BBO algorithm [3] in terms of non-dominated sorting of habitats is proposed. The modified algorithm (BiMO) makes it possible to approximate the Pareto front of the given design problem. The optimal shape design of an electrostatic micromotor, which is a benchmark in MEMS design, is considered as the case study.

## II. PROPOSED OPTIMIZATION METHOD

Computational bio-geography models the process of natural immigration and emigration of species between small islands in the search for more friendly habitats, which is observed in nature. Each solution considered in the relevant algorithm (BBO) is treated as a habitat (design vector) composed of suitability index variables (SIV, design variables), and each habitat exhibits a quality given by the habitat suitability index (HSI, objective function). Remarkably, in contrast to GA based algorithms, the original population is not discarded after each generation, but it is progressively modified by means of two stochastic operators, *i.e.* migration and mutation: migration improves the HSI of poor habitats by sharing features from good habitats; in turn, mutation modifies some randomly selected SIV of a few habitats in view of a better exploration of the ecosystem (design space). In practice, at each generation BBO exploits the HSI of each habitat based on its migration rate, while the emigration rate is set to be complementary to immigration. This way, the HSI of each habitat is improved.

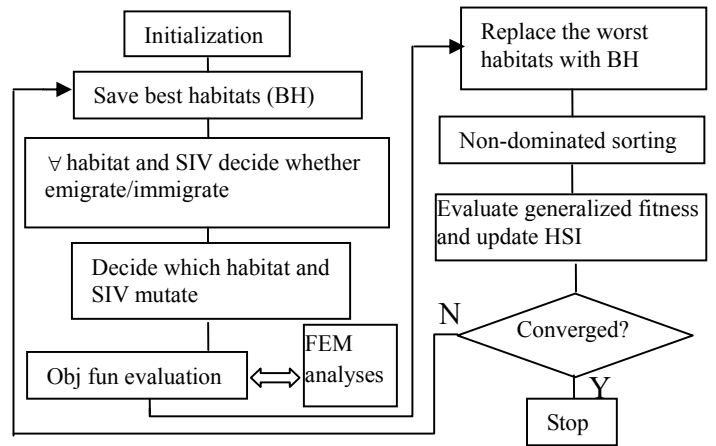


Fig. 1. Flow chart of the proposed BiMO algorithm.

In computational electromagnetics, applications and also modifications of BBO are an emerging new field of research: various single-objective problems of optimal design have been successfully solved; moreover, attempts to transform BBO in a multi-objective optimization algorithm have been considered [4-6]. In particular, the concept of predator-prey has been implemented [7] for hunting the worst individuals per objective function and making the surviving individuals spread in the objective space in order to escape from the predator. Though being interesting and effective, similar approaches might suffer from some limitations, like *e.g.* the possible loss of some non-dominated solutions (the worst individual per objective function might well be the end of the current set of non-dominated solutions), and the lack of an explicit criterion ruling the spread or crowd of the surviving individuals in the objective space.

As an alternative, in the paper it is proposed to modify the definition of HSI by means of a generalized fitness, which takes into account simultaneously two or more objective functions by exploiting the concept of non-dominated ranking of solutions in the objective space. In particular, elitism is exploited by preserving one half of the non-dominated habitats at each generation.

### III. CASE STUDY: OPTIMAL SHAPE DESIGN OF AN ELECTROSTATIC MICROMOTOR

The electrostatic micromotor exhibits 18 stator electrodes and 6 rotor teeth [8]. It had been prototyped with the following data: inner and outer rotor radii 40 and 60  $\mu\text{m}$ , stator radius 63  $\mu\text{m}$ , angular width of rotor slot  $40^\circ$  (Fig. 2, left). Accordingly, the width of the stator-to-rotor air-gap varies between 3 and 23  $\mu\text{m}$ . The stator electrodes are supplied by a three-phase system of square voltages, equal to 100 V, while the rotor potential is floating. The field domain is the air-gap region; to account for friction, the side-pull effect has been considered, caused by the radial displacement of the rotor during its motion. Actually, the eccentric motion determines an unbalanced electric pull, which appears as a radial force acting in the direction of the shortest air-gap. Based on Maxwell stress tensor method, the radial force  $F_r(\phi)$  acting on the rotor was evaluated as a function of its angular position  $\phi$ , in addition to the driving torque  $T_d(\phi)$  (Fig. 3). To simulate the radial displacement, a clearance between rotor and shaft equal to 1  $\mu\text{m}$  was considered; the direction of displacement was assumed to be fixed and independent of  $\phi$  (static eccentricity).

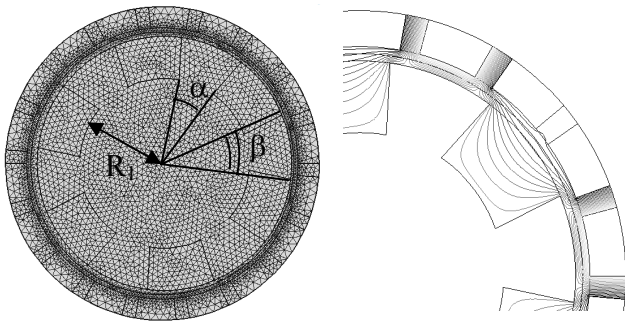


Fig. 2. Electrostatic micromotor: left – geometry and finite-element mesh (18,000 degrees of freedom) right – potential lines.

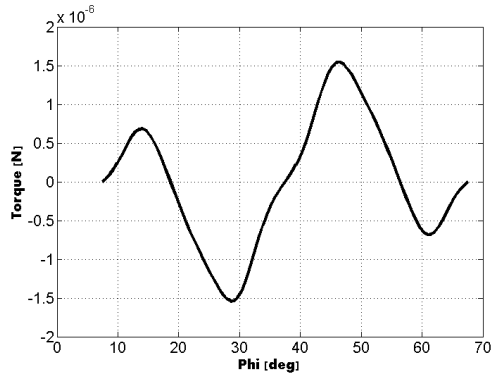


Fig. 3. Electrostatic micromotor: torque-angle curve on a pole pitch.

The shape design of the rotor has been considered, taking radius  $R_1$  and angles  $(\alpha, \beta)$  as the design variables. Significantly, two objective functions can be defined in terms of design vector  $g=(R_1, \alpha, \beta)$  namely:

- the highest value of driving torque on a pole pitch  $f_1(g)$  at no load under single-phase supply;
- the value of radial force on the rotor  $f_2(g)$  in the direction of the shortest air-gap.

The problem reads: given stator supply and rotor misalignment, find the family of rotor geometries  $g$  such that  $f_1(g)$  is maximum and  $f_2(g)$  is minimum according to the Pareto definition of non-dominated solution.

### IV. RESULTS

In Fig. 4 the approximated Pareto front found by means of BiMO method is shown (mutation probability set to 0.04, stopped after  $n_g=5$  generations, each based on  $n_p=14$  habitats); for the sake of a comparison, the front obtained by means of NSGA-II is also shown (stopped after  $n_g=5$  generations, each based on  $n_p=14$  individuals). For each method the overall cost is proportional to  $n_p \times n_g$  calls to the FEA.

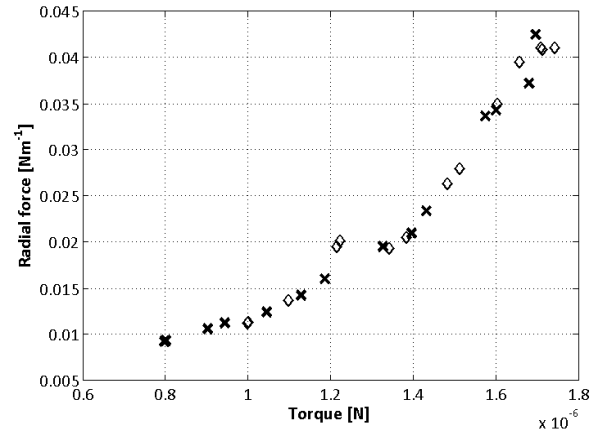


Fig. 4. Objective space and non-dominated solutions: cross – NSGA-II results, diamond – BiMO multi-objective results.

### V. CONCLUSION

The proposed method extends a standard bio-geography based optimization algorithm to the multi-objective case by modifying the definition of fitness. The optimal shape design of an electrostatic micromotor has been considered as the case study. To the best knowledge of the authors, the paper might be a pioneering contribution in the area of methods for MEMS design optimization.

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