Expert Systems with Applications 40 (2013) 5621–5634

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

# An improved electromagnetism-like mechanism algorithm for constrained optimization

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ARTICLE INFO

*Keywords:*
Constrained optimization
Electromagnetism-like mechanism algorithm
Feasibility and dominance rules

ABSTRACT

Many problems in scientific research and engineering applications can be decomposed into the constrained optimization problems. Most of them are the nonlinear programming problems which are very hard to be solved by the traditional methods. In this paper, an electromagnetism-like mechanism (EM) algorithm, which is a meta-heuristic algorithm, has been improved for these problems. Firstly, some modifications are made for improving the performance of EM algorithm. The process of calculating the total force is simplified and an improved total force formula is adopted to accelerate the searching for optimal solution. In order to improve the accuracy of EM algorithm, a parameter called as move probability is introduced into the move formula where an elitist strategy is also adopted. And then, to handle the constraints, the feasibility and dominance rules are introduced and the corresponding charge formula is used for biasing feasible solutions over infeasible ones. Finally, 13 classical functions, three engineering design problems and 22 benchmark functions in CEC'06 are tested to illustrate the performance of proposed algorithm. Numerical results show that, compared with other versions of EM algorithm and other state-of-art algorithms, the improved EM algorithm has the advantage of higher accuracy and efficiency for constrained optimization problems.



## 1. Introduction

Constrained global optimization problems are frequently encountered in science and engineering such as structural optimization, engineering design, VLSI design, economics, and management science (Kayhan, Ceylan, Ayvaz, & Gurarslan, 2010). Generally, these problems can be formulated mathematically as follows:

$$\begin{aligned}
&\min f(X)\\
&s.t\\
&g_k(X) \leqslant 0, \quad k = 1, 2, \ldots, m\\
&h_p(X) = 0, \quad p = 1, 2, \ldots, l\\
&X \in [L, U]\\
&[L, U] := \{X \in R^n | l_k \leqslant x_k \leqslant u_k, k = 1, \ldots, n\}
\end{aligned} \tag{1}$$

where $f$, $g$, $h$ are real-valued functions; $X = (x_1, x_2, \ldots, x_n)$ is a solution vector; $[L, U]$ is defined as a $n$-dimensional space with lower and upper bounds; $m$ and $l$ are the number of inequality and equality constraints, respectively. Normally, an equality constraint is dealt with an inequality constraint $|h(X)| - \varepsilon \leqslant 0$ for solving constrained optimization problems, where $\varepsilon$, which is a very small positive value, is the tolerance allowed.

When the objective functions and the constraints possess characteristics as high dimensions, non-convex, non-differentiable, and existing lots of local minimum, they are very hard to be solved by traditional methods such as augmented Lagrange multiplier method, sequential quadratic programming (SQP) algorithm and generalized reduced gradient algorithm. Recently, evolutionary algorithms incorporated with constraint handling techniques are very popular for constrained optimization problems. Methods dealing with constraints can be classified into the following categories (Takahama & Sakai, 2005):

(1) Methods based on preserving the feasible solutions. When a new search point generated in search process, is not feasible, the point is repaired or discarded. El-Gallad, El-Hawary, and Sallam (2001) proposed a method in which an infeasible point is replaced by the best visited point. In practice, the main difficulty in this category is the generation of a population of feasible points when the feasible region is small. Especially, it is almost impossible to find initial feasible points when the problems contain some equality constraints.
(2) Methods based on penalty functions. The penalty term, which is the sum of the violation of all constraint functions, is combined with the objective function. The original

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http://dx.doi.org/10.1016/j.eswa.2013.04.028

constrained problem is solved as an unconstrained one by this method. The main difficulty here is the setting of the penalty parameter. If the penalty parameter is large, feasible solutions with low accuracy can be obtained. If the penalty parameter is small, high-quality but infeasible solutions can be obtained. Several methods of updating the penalty parameter dynamically have been proposed. But it is difficult to determine a general control model because of problem dependence.

(3) Methods based on basing feasible over infeasible solutions. The constraint violation and the objective function are used separately and optimized by some sort of order in which the constraint violation precedes the objective function. Deb (2000) proposed three simple rules for tournament selection in genetic algorithms where two solutions were compared. Three rules, so-called feasible and domain (FAD) rules, drive the points in the direction from unfeasible region to feasible region which were used widely in literature. Runarsson and Yao (2000) proposed a stochastic ranking method in which the stochastic order, which ignored the constraint violation with some probability, was used. These methods seem to be nowadays the most used strategies for handing constraints.

(4) Methods based on multi-objective optimization concepts. The constrained optimization problems are solved as the multi-objective optimization problems by treating the constraint violation as another objective function (Aguirre, Rionda, Coello, Lizárraga, & Montes, 2004). However, solving multi-objective optimization problems is more difficult and expensive than solving single objective optimization problems. What is more, Runarsson and Yao (2005) proved that the unbiased multi-objective approach to constraint handling may not be effective by theoretical analysis and experimental studies.

In this paper, a constraint handling technique for biasing feasible over infeasible solutions is implemented into the improved electromagnetism-like mechanism (EM) algorithm. EM algorithm, a population based meta-heuristic search algorithm for unconstrained optimization problems, was first proposed by Birbil and Fang (2003). It has been applied to solve many optimization problems successfully, such as neural network training (Wu, Yang, & Wei, 2004), circle detection (Cuevas, Oliva, Zaldivar, Marco, & Sossa, 2012), PID controller optimization (Lee & Chang, 2010), job shop scheduling (Tavakkoli-Moghaddam, Khalili, & Naderi, 2009), unicost set covering problem (Naji-Azimi, Toth, & Galli, 2010), feature selection (Su & Lin, 2011). It is proved EM algorithm is a powerful and promising global optimization method.

Based on the literature review, there exist five papers about EM algorithm for constrained optimization problems. Birbil (2002) used a simple penalty based method to handle constraints in EM algorithm. Three papers presented EM algorithm for constrained optimization problems by Rocha and Fernandes (2008a, 2008b, 2009a). The first one presented the use of the feasible and dominance (FAD) rules in EM algorithm (Rocha & Fernandes, 2008a). The second one incorporated the elite-based local search in EM algorithm for engineering optimization problems and the FAD rules were used again (Rocha & Fernandes, 2008b). A self-adaptive penalty approach for dealing with constraints within EM algorithm was proposed in the third paper (Rocha & Fernandes, 2009a). Since the FAD rules were simple and efficient for constraints handling, they were also applied in Ali's paper where another EM algorithm was applied for nonlinearly constrained global optimization (Ali & Golalikhani, 2010). The highlight of Ali's paper was the charge calculation based on both the function value and the total constraint violations. The results of 13 benchmark test problems proved that Ali's method outperform other versions of EM for constrained problems (Ali & Golalikhani, 2010).

However, the efficiency of EM algorithm is not satisfactory because the process of calculating total force is rather complicated. And its precision is limited. For example, the constrained EM version proposed by Ali still cannot catch up with some other state-of-the-art algorithms, such as particle swarm optimization (PSO) algorithms. In order to further improve the precision and efficiency of EM algorithm for constrained optimization, modifications on algorithm itself or constraint-handling technique must be made. Many good works about the modification of EM algorithm have been reported. Rocha and Fernandes (2008c, 2009b) modified the calculation of the charge and introduced a pattern-search-based local search. They also proposed a modification of calculation of total force vector (Rocha & Fernandes, 2009c). Gol-Alikhani, Javadian, and Tavakkoli-Moghaddam (2009) investigated a hybridization of EM algorithm and Solis & Wets local search algorithm, to some extent, which improves the accuracy of EM algorithm. But those modifications made no contribution to the simplification of EM algorithm, some of which contrarily made EM algorithm more complicated. Therefore, this paper tries to simplify the process of EM algorithm and improve its performance. Firstly, a simplified calculation of total force vector is proposed, to reduce the complexity of the algorithm. And then, movement probability is imported to modify the move formula where an elitist strategy is adopted.

The remainder of the paper is organized as follows. The improved EM algorithm is introduced in Section 2. And then, the constraint handling techniques and the flowchart are introduced in Section 3. Section 4 presents experimental results on 13 benchmark problems, three engineering design problems and 22 benchmark functions in CEC'06. Finally, the conclusion and suggestions for future work are provided in Section 5.

## 2. The improved electromagnetism-like mechanism algorithm

EM algorithm was first proposed for unconstrained optimization problems (Birbil & Fang, 2003). It cannot be applied for constrained optimization problems directly. Therefore, in order to use EM algorithm to solve constrained optimization problems, firstly, some improvements are made from Sections 2.2 to 2.3 for satisfying both high accuracy and high efficiency in EM algorithm. Secondly, the constraint handling methods including FAD rules and new charge calculation formula must be added into EM algorithm, which is introduced in Section 3. The next section introduces the original EM algorithm briefly.

### 2.1. The original EM algorithm

The algorithm imitates the attraction–repulsion mechanism of the electromagnetism theory so it is called electromagnetism-like mechanism algorithm. A solution in EM algorithm can be seen as a charged particle in search space and its charge relates to the objective function value. Electromagnetic force exists between two particles. With the force, the particle with more charge will attract the other and the other one will repulse the former. The charge also determines the magnitude of attraction or repulsion – the better the objective function value, the higher the magnitude of attraction or repulsion.

There are four phases in EM algorithm: initialization of the algorithm, calculation of the total force, movement along the direction of the force and neighborhood search to exploit the local minima. Fig. 1 shows the EM's general scheme.

#### 2.1.1. Initialization

In the primary initialization part, a population is randomly generates in the search space as same as other population-based