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Electromagnetic field optimization: A physics-inspired metaheuristic optimization algorithm

Hosein Abedinpourshotorban [a,b], Siti Mariyam Shamsuddin [a], Zahra Beheshti [a], Dayang N.A. Jawawi [b]

[a] UTM Big Data Centre, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
[b] Department of Software Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

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ABSTRACT

This paper presents a physics-inspired metaheuristic optimization algorithm, known as Electromagnetic Field Optimization (EFO). The proposed algorithm is inspired by the behavior of electromagnets with different polarities and takes advantage of a nature-inspired ratio, known as the golden ratio. In EFO, a possible solution is an electromagnetic particle made of electromagnets, and the number of electromagnets is determined by the number of variables of the optimization problem. EFO is a population-based algorithm in which the population is divided into three fields (positive, negative, and neutral); attraction–repulsion forces among electromagnets of these three fields lead particles toward global minima. The golden ratio determines the ratio between attraction and repulsion forces to help particles converge quickly and effectively. The experimental results on 30 high dimensional CEC 2014 benchmarks reflect the superiority of EFO in terms of accuracy and convergence speed over other state-of-the-art optimization algorithms.

1. Introduction

Metaheuristic algorithms are used to find an approximate optimal solution for difficult optimization problems, for which there is no deterministic method to solve them within a reasonable time. A metaheuristic algorithm is defined as a problem independent algorithm that can find approximate solutions to hard problems. Metaheuristics are inspired by nature and try to solve problems by mimicking ethology, biology, or physics [1].

Evolutionary algorithms (EAs) are stochastic, population-based metaheuristic algorithms. EAs differ from some optimization methods, such as Simulated-Annealing [2] and Tabu search [3], because they evolve a population of solutions to reach an approximate optimal solution instead of one solution [4]. Generally, EAs search the problems domain as follows: a population of random individuals (solutions) is initialized for the first time, and then the fitness of individuals are evaluated by the fitness function. In the next generations, individuals evolve towards the global best solution by means of EAs and the guidance of the fitness function. This process continues until it reaches the maximum number of iterations or finds the expected near-optimum solution.

The ability to balance between exploration (diversification) and exploitation (intensification) plays a significant role in the success of an EA. Exploitation is required to explore the problem surface globally and identify the area of the search space that contains the global best solution (global minima). Exploitation is required to find an accurate solution by intensifying the search in the area that is determined by the exploration stage. Achievement of this balance is the main characteristic of EAs and the way they differ from each other [5]. Generally, EAs are more exploration-oriented rather than exploitation oriented. This characteristic makes them suitable for hard problems with lots of local optimal solutions (local minima) because they keep a population of solutions and investigate a large area to find the global best solution.

Several well-known, nature-inspired EAs are: Genetic Algorithm (GA), which works based on the principle of the Darwinian theory of survival [6,7], Particle Swarm Optimization (PSO) [8–11], which works based on the foraging behavior of a swarm of birds [7], Differential Evolution (DE) [12], which is similar to GA with modified crossover and mutation methods, and Harmony Search (HS) [13,14], which works based on the way that musicians experiment and change their instruments' pitches to improvise better harmonies. These well-known optimization algorithms

E-mail addresses: h_abedinpour@gmail.com (H. Abedinpourshotorban), mariyam@utm.my (S. Mariyam Shamsuddin), bzahra2@live.utm.my (Z. Beheshti), dayang@utm.my (D.N.A. Jawawi).

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have been applied for the optimization of many optimization problems [15] and have demonstrated acceptable accuracy and speed. However, the challenge in this area is how to be inspired from the existing knowledge about optimization and the way in which nature behaves to improve the existing algorithms or develop a new algorithm, which can quickly find the best solution globally while avoiding optimal solutions locally.

Two recently proposed nature-inspired optimization algorithms are Artificial Bee Colony (ABC) [16,17] and Group Search Optimizer (GSO) [18]. ABC is an optimization algorithm based on the intelligent foraging behavior of honey bee swarms, and the GSO algorithm is inspired by animals' food search behavior. Both algorithms have been successfully applied to various optimization problems and have demonstrated competitive search power.

Physics-inspired heuristics are another type of EAs, that are motivated by physics laws. In 2008, Tayarani [15,19] proposed a magnetic-inspired optimization algorithm called Magnetic Optimization Algorithm (MOA), which is inspired by the attraction force among magnetic particles. In MOA, possible solutions are presented by magnets with different mass, which are scattered in a lattice-like structure all over the search space and apply a force of attraction to their neighbors, according to their fitness. A similar algorithm to MOA is the Gravitational Search Algorithm (GSA) [20], which considers the search agents (particles) as masses that attract each other based on the gravitational forces between them. Some other recent algorithms have used a similar idea for optimization based on the physics-inspired laws of forces. Magnetic Charged System Search (MCSS) [21] utilizes the governing laws for magnetic forces in addition to electrical forces for optimization. Ions Motion Optimization (IMO) [22] is proposed based on the attraction and repulsion of anions and cations to perform optimization.

Motivated by the previously proposed force-based algorithms and the fact that in most of them, particles are attracted to the fittest particle, which increases the chances of finding local minima, this paper proposes a physics-inspired optimization algorithm called Electromagnetic Field Optimization (EFO), which is inspired by two phenomena. The first phenomenon is the attraction–repulsion forces among electromagnets with different polarities, and the second phenomenon is a nature-inspired ratio called the golden ratio [23], which is also known as god's fingerprint. In our algorithm, particles move a distance away from particles with low fitness (bad solutions) and get closer to the fittest particles (good solutions) based on the attraction–repulsion forces among three electromagnetic fields. The repulsion force helps particle to avoid local minima and the attraction force leads particles toward global minima. Experimental results on the CEC 2014 benchmarks show that our proposed algorithm outperforms existing algorithms.

2. Electromagnetic field optimization

An electromagnet is a type of magnet in which electrical current produces a magnetic field. In contrast to the permanent magnet, an electromagnet has single polarity (positive or negative), which is determined by the direction of the electrical current and can be changed by changing the direction of the electrical current. Moreover, there are two different forces among electromagnets: attraction and repulsion. Electromagnets with the same polarity repel each other, and those with opposite polarity attract each other. The attraction force among electromagnets is (5–10%) stronger than the repulsion force. Our algorithm uses these concepts and replaces the ratio between attraction and repulsion forces with the golden ratio. This helps particles to adequately investigate the problem search space and find a near-optimal solution.

EFO is a population-based algorithm and each solution vector is represented by one group of electromagnets (electromagnetic particle). The number of electromagnets of an electromagnetic particle is determined by the number of variables of the optimization problem. Therefore, each electromagnet of the electromagnetic particle corresponds to one variable of the optimization problem. Moreover, all electromagnets of the same electromagnetic particle have the same polarity. However, each electromagnet can apply a force of attraction or repulsion on the peer-electromagnets that correspond to the same variable of the optimization problem.

EFO searches the problems domain as follows: first, a population of electromagnetic particles is generated randomly, and the fitness of each particle is evaluated by a fitness function; then, particles are sorted according to their fitness. Second, sorted particles are divided into three groups, and a portion of the electromagnetic population is allocated to each group; the first group is called the positive field and consists of the fittest electromagnetic particles with positive polarity, the second group is called the the negative field and consists of the electromagnetic particles with the lowest fitness and negative polarity, and the remaining electromagnetic particles form a group called the neutral field, which has a small negative polarity almost near zero. Finally, in each iteration of the algorithm, a new electromagnetic particle is shaped and evaluated by a fitness function. If the generated electromagnetic particle is fitter than the worst electromagnetic particle in the population, then the generated particle will be inserted into the sorted population according to its fitness and obtain a polarity based on its position in the population; moreover, the worst particle will be eliminated. This process continues until it reaches the maximum number of iterations or finds the expected near-optimal solution.

EFO determines the position of each electromagnet of a generated electromagnetic particle as follows: from the electromagnetic particles of each electromagnetic field (positive, negative, and neutral), three peer electromagnets are randomly selected (one electromagnet from each field). Afterwards, the generated electromagnet gets the position and polarity (small negative polarity) of the selected electromagnet from the neutral

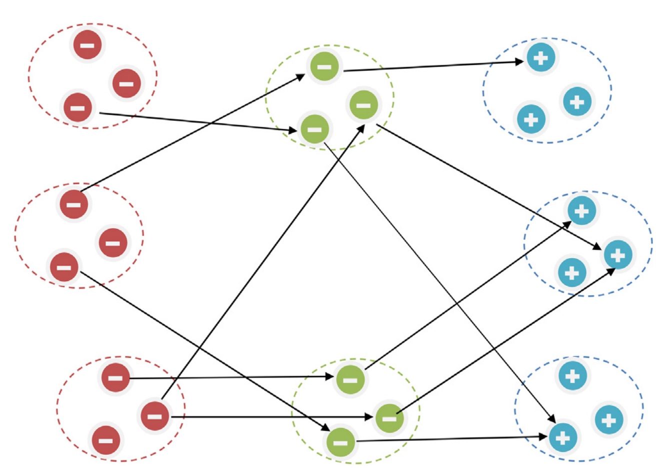

Fig. 1. Direction of forces among electromagnets. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)