Information Sciences 293 (2015) 125–145

Contents lists available at ScienceDirect

Information Sciences

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

# A new metaheuristic for numerical function optimization: Vortex Search algorithm

Berat Doğan *, Tamer Ölmez

*Istanbul Technical University, Department of Electronics and Communication Engineering, Turkey*

ARTICLE INFO

*Article history:*
Received 4 December 2013
Received in revised form 22 August 2014
Accepted 27 August 2014
Available online 18 September 2014

*Keywords:*
Metaheuristics
Global optimization
Function optimization
Simulated annealing
Artificial bee colony
Particle swarm optimization

ABSTRACT

In this study, a new single-solution based metaheuristic, namely the Vortex Search (VS) algorithm, is proposed to perform numerical function optimization. The proposed VS algorithm is inspired from the vortex pattern created by the vortical flow of the stirred fluids. To provide a good balance between the explorative and exploitative behavior of a search, the proposed method models its search behavior as a vortex pattern by using an adaptive step size adjustment scheme. The proposed VS algorithm is tested over 50 benchmark mathematical functions and the results are compared to both the single-solution based (Simulated Annealing, SA and Pattern Search, PS) and population-based (Particle Swarm Optimization, PSO2011 and Artificial Bee Colony, ABC) algorithms. A Wilcoxon-Signed Rank Test is performed to measure the pair-wise statistical performances of the algorithms, the results of which indicate that the proposed VS algorithm outperforms the SA, PS and ABC algorithms while being competitive with the PSO2011 algorithm.



## 1. Introduction

Many real-life optimization problems are complex in their nature and are difficult to solve. Exact optimization methods usually cannot provide a solution for these types of optimization problems. Some of the properties of such problems, such as high dimensionality, multimodality, epistasis (parameter interaction), and non-differentiability, render exact optimization methods impotent [41]. Hence, the use of some approximate algorithms remains as an alternative approach for the solution of these problems.

Approximate algorithms can be further decomposed into two classes: specific heuristics and metaheuristics [41]. Specific heuristics are problems dependent and designed only for the solution of a particular problem. However, metaheuristics represent a family of approximate algorithms that are more general and thus applicable to a large variety of optimization problems.

The words "meta" and "heuristic" both have their origin in the old Greek: "meta" means "upper level", and "heuristic" denotes the art of discovering new strategies [41]. Heuristic methods provide near optimal solutions in a reasonable amount of computational time without guaranteeing the optimality. Thus, the term metaheuristics can be defined as some intelligent strategies that enhance the efficiency of the heuristic methods [6].

A number of classification criteria have been proposed in the literature for the metaheuristics classification, including the search path that they follow, the use of memory, the type of neighborhood exploration used or the number of current

* Corresponding author.
*E-mail addresses:* bdogan@itu.edu.tr (B. Doğan), olmezt@itu.edu.tr (T. Ölmez).

http://dx.doi.org/10.1016/j.ins.2014.08.053
0020-0255/

**Input:** Initial solution $s_0$
$t = 0$;
**Repeat**
  /* Generate candidate solutions (partial or complete neighborhood) from $s_t$ */
  Generate( $C(s_t)$ ) ;
  /* Select a solution from $C(s)$ to replace the current solution $s_t$ */
  $s_{t+1}$ = Select( $C(s_t)$ ) ;
  $t = t + 1$;
**Until** the termination condition is met.
**Output:** Best solution found

**Fig. 1.** High-level representation of the single-solution based metaheuristics.

solutions transferred from one iteration round to the next. Among these criteria, the metaheuristic classification, which differentiates between the Single-Solution Based Metaheuristic and the Population-Based Metaheuristic, is often taken to be a fundamental distinction in the literature [41,8]. Single-solution based metaheuristics are also known as trajectory methods, which are based on a single solution at any time and comprise local search-based metaheuristics such as Simulated Annealing (SA) [30,9], Tabu Search (TS) [18], Iterated Local Search (ILS) [33], Guided Local Search (GLS) [3], Pattern Search (PS) [22], Random Search (RS) [36], and Variable Neighborhood Search (VNS) [20]. However, in population-based metaheuristics, a number of solutions is first created and then updated iteratively until the termination condition is satisfied. Population-based metaheuristics are generally studied under two major groups: Evolutionary algorithms and Swarm-based algorithms. Evolutionary algorithms are based on the notion of natural selection, which can be considered a competition between the species during the evolution process. In these algorithms, individual solutions are selected from a population of solutions according to their fitness value to generate new offspring by using some operators, such as the crossover and the mutation operators. Some well-known examples of the evolutionary algorithms are the Genetic Algorithm (GA) [21], Differential Evolution (DE) [39,40], and Estimation of Distribution Algorithms (EDA) [31]. Swarm- based algorithms are another class of population-based metaheuristics, which are inspired by the collective behavior of species, such as ants, bees, fish and birds. Swarm-based algorithms have the following characteristics: their particles are simple and non-sophisticated agents, they cooperate by an indirect communication medium, and they perform movements in the decision space [41]. Ant Colony Optimization (ACO) [12], Particle Swarm Optimization (PSO) [29] and Artificial Bee Colony algorithm (ABC) [5,25–27] are well-known examples of the swarm-based algorithms.

In the past two decades, both the single-solution based and population-based metaheuristics have been successfully applied to many real-world optimization problems. These algorithms produce solutions by exploring the search space efficiently while reducing the effective size of the search. Thus, the success of a metaheuristic method on a given optimization problem is defined by its ability to provide a good balance between the exploration and exploitation. The exploration defines the global search ability of the algorithm, whereas the exploitation is the ability to find the optimum around a near-optimal solution, which can also be considered as the local search ability. Because there is no any information provided regarding the search space in the initial steps, more exploration is required. However, as the algorithm converges to a near-optimal solution, more exploitation is required to tune the current solution towards the optimal one. The main differences between the existing metaheuristics concern the particular manner in which they attempt to achieve this balance [8]. Single-solution based metaheuristics are accepted to be more exploitation oriented, whereas population-based metaheuristics are more exploration oriented.

In this study, we propose a new single-solution based metaheuristic, namely, the Vortex Search (VS) algorithm, for the solution of bound-constrained global optimization problems. The proposed algorithm can be studied within the family of the search algorithms that comprises the Random Search and Pattern Search algorithms. The Random Search algorithm (which is also known as the Fixed Step Size Random Search) was proposed by Rastrigin [36], who introduced RS along with a basic mathematical analysis. RS functions by iteratively moving to better positions in the search space that are sampled from a hypersphere surrounding the current position. The PS, which was proposed by Hooke and Jeeves is a type of algorithm similar to the RS [38]. The problem with the above-mentioned algorithms is "the step size", which significantly affects the performance of the algorithms. To overcome this problem, a number of RS variants (e.g., Optimum Step Size Random Search (OSSRS) [38], Adaptive Step Size Random Search (ASSRS) [38], Optimized Relative Step Size Random Search (ORSSRS) [37]) were proposed. However, none of these algorithms could challenge the performance of population-based metaheuristics. Here, the proposed VS algorithm uses a new adaptive step size adjustment scheme that considerably improves the performance of the search process. Because the search behavior of the VS algorithm is inspired from the vortex pattern, we named the newly proposed algorithm the "Vortex Search" algorithm.

The proposed algorithm was tested on the 50 benchmark mathematical optimization functions and the obtained results were compared to the results found by the SA, PS, PSO2011, and ABC algorithms. The proposed VS algorithm was found to outperform the two single-solution based algorithms of SA and PS and a population-based algorithm ABC, while being competitive with another population-based algorithm, PSO2011. Because the proposed VS algorithm is very simple, this leads to a decrease in the computational time of the 50 benchmark functions when compared to the population-based algorithms.