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A chaos-based evolutionary algorithm for general nonlinear programming problems

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ABSTRACT

In this paper we present a chaos-based evolutionary algorithm (EA) for solving nonlinear programming problems named chaotic genetic algorithm (CGA). CGA integrates genetic algorithm (GA) and chaotic local search (CLS) strategy to accelerate the optimum seeking operation and to speed the convergence to the global solution. The integration of global search represented in genetic algorithm and CLS procedures should offer the advantages of both optimization methods while offsetting their disadvantages. By this way, it is intended to enhance the global convergence and to prevent to stick on a local solution. The inherent characteristics of chaos can enhance optimization algorithms by enabling it to escape from local solutions and increase the convergence to reach to the global solution. Twelve chaotic maps have been analyzed in the proposed approach. The simulation results using the set of CEC'2005 show that the application of chaotic mapping may be an effective strategy to improve the performances of EAs.

1. Introduction

Nonlinear programming problems, are very important and frequently appear in the real world applications, such as structural optimization, engineering design, very-large-scale cell layout design, economics, resource allocation and many other applications [1–2]. Traditionally, the nonlinear programming problems are divided into two large classes: unconstrained optimization problems and constrained optimization problems, involving at least one inequality or equality constraint [2]. Unfortunately, there is no known method of determining the global optimal to the general nonlinear programming problem. For the unconstrained optimization problems there are many techniques which are classified to direct search methods and gradient based methods, while the constrained optimization problem algorithms are classified to indirect and direct methods. All of these methods are called traditional optimization techniques, which are local in scope, depending on the existence of derivatives, and they are insufficiently robust in discontinuous, vast multimodal, and noisy search spaces [3].

Some optimization methods that are conceptually different from the traditional optimization techniques have been appeared labeled as modern or non-traditional optimization techniques and are emerging as popular methods for the solution of complex engineering problems. These methods are based on certain characteristics and behavior of biological, molecular, swarm of insects, and neurobiological systems. Furthermore, non-traditional optimization techniques overcome difficulties and limitations of traditional techniques and are less susceptible to getting 'stuck' at local optimal. In addition they require fewer parameters without requiring the objective function to be derivable or even continuous [4].

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Among the existing non-traditional techniques, well-known algorithms such as simulated annealing (SA) [5,6], genetic algorithms (GA) [7,8], particle swarm optimization (PSO) [9,10], ant colony optimization (ACO) [11–13], neural-network-based methods [14,15], and fuzzy optimization [16,17], etc. GA is one of the non-traditional methods and is presented as an efficient global method for nonlinear programming problems. GAs are well suited for solving such problems and it enjoys an increasing interest in the optimization community and many industrial applications [18-20]. New researchers introduced improved methods based on the hybridizing algorithms with genetic algorithms to improve its results. For instance, Tsoulos [21] introduced a heuristic modified method based on the genetic algorithm for solving constrained optimization problems. Juan and Ping [22] optimized the fuzzy rule base with combination of the GA and ant colony. Additionally, Sun and Tian [23] developed an efficient hybrid method for image classification with PSO and GA; where the authors used features of fast convergence of PSO and diversity of GA to improve the results quality.

On the other hand, GAs can escape from local optima traps and find the global optima regions. However, their intensification process near the optimum set is often inaccurate. Thus, various approaches have been created to improve the local search capability of genetic algorithm by hybridizing it with local search techniques [24–29]. Donis-Díaz et al. [24] introduced a hybrid model of GA with local search and show that the hybrid model improves the results compared to those obtained by using the classical model of GA. Sawyerr et al. [25] improved the local search capability of GA by hybridizing real coded genetic algorithm with 'uniform random' local search. In [26], Yang et al. developed a hybrid algorithm which is a combination between genetic algorithm and local search to solve the parametric mixed-integer programming problem; where GA is used to perform global search, while LS strategy is applied to each generated individual (or chromosome) of the population. Furthermore, Derbel et al. [27] proposed a combination between GA and an iterative local search to improve the solutions generated by GA and intensify the search space. In addition, Derbel et al. show by numerical experiments that hybrid algorithm improves the best known solutions previously obtained by the tabu search. Kabir et al. [28] incorporated a new local search operation that is devised and embedded in hybrid genetic algorithm to fine-tune the search in feature selection process. Finally, in [29] Kilani makes a comparison between the performance of the genetic and local search algorithms for solving the satisfiability problems.

In the recent years, the mathematics of chaos theory has been applied to many aspects of the optimization sciences. Chaos theory was initially described by Hénon [30] and was summarized by Lorenz [31]. It has many applications that include meteorology, sociology, physics, engineering, economics, biology, and philosophy. Chaos is a common nonlinear phenomenon in nature, where it is fully reflects the complexity of the system that will be useful in optimization. Chaotic maps can easily be implemented and avoid entrapment in local optimal [32–36]. As a novel method of global optimization, chaos optimization algorithms have attracted much attention, which were all based on Logistic map. In [37] an experimental analysis on the convergence of EAs is proposed; where the effect of introducing chaotic sequences instead of random ones during all the phases of the evolution process is investigated. Tavazoei and Haeri in [38] proposed a new optimization technique by modifying a chaos optimization algorithm (COA) based on the fractal theory. Additionally, by considering the statistical property of the sequences of Logistic map and Kent map, Yang et al. [39] proposed an improved hybrid chaos-Broyden-Fletcher-Goldfarb-Shanno (BFGS) optimization algorithm and the Kent map based hybrid chaos-BFGS algorithm. While, in [40] Cong et al. proposed an improved fast convergent chaos optimization algorithm based on the ergodic and stochastic properties of the chaos variables; which is more effective in complex optimization problems.

Many researchers proposed integration between chaos theory and optimization algorithms to improve the solution quality [41–47]. The authors in [41] presented hybrid chaos-PSO algorithm for the vehicle routing problem with time window. While, in [42] chaotic genetic algorithm based on Lorenz chaotic system for optimization problems was proposed. In [43] an improved quantum EA is presented based on PSO and chaos to avoid the disadvantage of easily getting into the local optional solution in the later evolution period. In [44] a new PSO method that uses chaotic maps for parameter adaptation is presented; where eight chaotic maps have been analyzed in the benchmark functions and twelve chaos-embedded PSO methods have been proposed. While, Zelinka et al. [45] discussed the mutual intersection of evolutionary computation and deterministic chaos; where evolutionary computation is explored, and deterministic chaos is investigated as a behavioral part of EAs. Moreover, in [46] an effective self-adaptive differential evolution algorithm based on Gaussian probability distribution, gamma distribution and chaotic sequence (DEGC) for solving continuous global optimization problems is proposed. Chaotic sequences are applied in [47] to generate candidate solutions and a new searching mechanism is used to generate new solutions.

EAs are powerful computing tools to solve large-scale problems that have many local optima. However, they require high CPU times that are unpractical from the engineering viewpoint, and they can escape from local optima traps and find the global optima regions. However, their intensification process near the optimum set is often inaccurate. On the other hand, local search schemes can converge quickly to these local minima and get stuck in a local optimum solution far away from the global optimal.

In this paper, we present a chaos-based EA for solving nonlinear programming problems. The proposed algorithm is new optimization system that integrates GA with CLS strategy. The inherent characteristics of chaos can enhance optimization algorithms by enabling it to escape from local solutions and increase the convergence to reach to the global solution [48]. Twelve chaotic maps have been analyzed in the proposed approach. By this way, it is intended to enhance the global convergence and to prevent to stick on a local solution. It has been detected that coupling with chaotic maps save computational time and speed