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FULL-LENGTH ARTICLE

Solving stochastic programming problems using new approach to Differential Evolution algorithm

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Abstract This paper presents a new approach to Differential Evolution algorithm for solving stochastic programming problems, named DESP. The proposed algorithm introduces a new triangular mutation rule based on the convex combination vector of the triangle and the difference vector between the best and the worst individuals among the three randomly selected vectors. The proposed novel approach to mutation operator is shown to enhance the global and local search capabilities and to increase the convergence speed of the new algorithm compared with conventional DE. DESP uses Deb's constraint handling technique based on feasibility and the sum of constraint violations without any additional parameters. Besides, a new dynamic tolerance technique to handle equality constraints is also adopted. Two models of stochastic programming (SP) problems are considered: Linear Stochastic Fractional Programming Problems and Multi-objective Stochastic Linear Programming Problems. The comparison results between the DESP and basic DE, basic particle swarm optimization (PSO), Genetic Algorithm (GA) and the available results from where it is indicated that the proposed DESP algorithm is competitive with, and in some cases superior to, other algorithms in terms of final solution quality, efficiency and robustness of the considered problems in comparison with the quoted results in the literature.

1. Introduction

Stochastic or probabilistic programming (SP) deals with situations where some or all of the parameters of the optimization problem are described by random or probabilistic variables rather than by deterministic quantities [1]. The mathematical models of these problems may follow any particular probability distribution for model coefficients [2]. The main objective is to find the optimal value for model parameters influenced by random event. The basic idea used in stochastic programming is to convert the stochastic problem into an equivalent deterministic problem which can be solved by using an appropriate classical and/or modern numerical technique. SP is widely used in many real-world decision making problems of management science, engineering, and technology. Also, it has been applied to various areas such as finance [3], manufacturing product

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and capacity planning [4], electrical generation capacity planning [5], supply chain management [6], water resource allocation modeling [7], portfolio selection [8], project selection [9], transportation [10], Telecommunications [11], energy planning [12], healthcare management [13] and marketing [14]. A constrained linear stochastic fractional programming (LSFP) problem involves optimizing the ratio of two linear functions subject to some constraints in which at least one of the problem data is random in nature with nonnegative constraints on the variables. In addition, some of the constraints may be deterministic. Thus, the LSFP framework attempts to model uncertainty in the data by assuming that the input or a part thereof is specified by a probability distribution, rather than being deterministic [15]. There are many algorithms to solve LSFPP such as [16–19]. Moreover, SP has been applied to the problems having multiple, conflicting and non-commensurable objectives where generally there does not exist a single solution which can optimize all the objectives [20]. Various algorithms to solve Multiobjective Stochastic Linear Programming (MOSLP) problems have been discussed in the literature [20–23]. On the other hand, over the last three decades, Evolutionary Algorithms (EAs) have been developed to solve nonlinear, high-dimensional and complex computational optimization problems. Virtually, EAs have been originally proposed to overcome the challenges of global optimization problems such as nonlinearity, non-convexity, non-continuity, non-differentiability, and/or multimodality, while traditional numerical optimization techniques had difficulties with these problems. Differential Evolution (DE) is a stochastic population-based search method, proposed by Storn and Price [24]. DE is considered the most recent EAs for solving real-parameter optimization problems [25]. While DE shares similarities with other EAs, it differs significantly in the sense that in DE, distance and direction information is used to guide the search process [26]. In this research, two models of stochastic programming (SP) problems are considered: Linear Stochastic Fractional Programming Problems and Multi-Objective Stochastic Linear Programming Problems. For LSFPP and MOSLP, the models proposed by Charles and Dutta [19] and by Charles et al. [20], respectively, are followed. The deterministic equivalent models of these two classes of stochastic programming models are solved using a new approach to Differential Evolution algorithm, named DESP. The proposed algorithm introduces a new triangular mutation rule based on the convex combination vector of the triangle and the difference vector between the best and the worst individuals among the three randomly selected vectors. The proposed novel approach to mutation operator is shown to enhance the global and local search capabilities and to increase the convergence speed of the new algorithm compared with conventional DE. DESP uses Deb's constraint handling technique based on feasibility and the sum of constraint violations without any additional parameters. Besides, a new dynamic tolerance technique to handle equality constraints is also adopted. The results obtained by DESP algorithms are compared with basic versions of DE and PSO and also with the results quoted in the literature [19,20]. It is worth noting that although this work is an extension and modification of our previous work in [27], there are significant differences as follows: (1) previous work in [27] is proposed for unconstrained problems, whereas this work is proposed for constrained problems. Hence, (2) a new dynamic tolerance technique to handle equality constraints is also adopted, (3) the crossover rate in [27] is given by a dynamic nonlinear increased probability scheme, but in this work, the crossover rate is fixed 0.95. (4) The triangular mutation rule is only used in this work, but in the previous work [27], the triangular mutation strategy is embedded into the DE algorithm and combined with the basic mutation strategy DE/rand/1/bin through a nonlinear decreasing probability rule. (5) In previous work [27] a restart mechanism based on Random Mutation and modified BGA mutation is used to avoid stagnation or premature convergence, whereas this work does not. The remainder of this paper is organized as follows: Section 2 presents the problem of our interest and the Deb's procedure for handling constraints. In Section 3, the standard DE algorithm is introduced with a review of its operators and parameters. Next, in Section 4, the proposed DESP algorithm is described. The problem definitions are given in Section 5. In Section 6, the effectiveness of the proposed method, the experimental settings and numerical results are discussed. Finally, the conclusions and future works are drawn in Section 7.

2. Problem statement

In general, constrained optimization problem can be expressed as follows (without loss of generality minimization is considered here):

$$\text{Minimize} \quad f(\vec{x}), \quad \vec{x} = (x_1, x_2, \ldots, x_n) \in \Re^n \tag{1}$$

Subject to:

$$g_j(\vec{x}) \leqslant 0, \quad j = 1, \ldots, q \tag{2}$$

$$h_j(\vec{x}) = 0, \quad j = q+1, \ldots, m \tag{3}$$

where $\vec{x} \in \Omega \subseteq S$, Ω is the feasible region, and S is an n-dimensional rectangular space in $\Re^n$ defined by the parametric constraints $l_i \leqslant x_i \leqslant u_i, 1 \leqslant i \leqslant n$ where l_i and u_i are lower and upper bounds for a decision variable x_i, respectively. For an inequality constraint that satisfies $g_j(\vec{x}) \leqslant 0$ $(j \in 1, \ldots, q)$ at any point $\vec{x} \in \Omega$, we say it is active at $\vec{x}$. All equality constraints $h_j(\vec{x}) = 0, (j = q+1, \ldots, m)$ are considered active at all points of Ω. Most constraint-handling approaches used with EAs tend to deal only with inequality constraints. Therefore equality constraints are transformed into inequality constraints of the form $\left|h_j(\vec{x})\right| - \varepsilon \leqslant 0$ where ε is the tolerance allowed (a very small value) [28]. In order to handle constraints, we use Deb's constraint handling procedure. Deb [29] proposed a new efficient feasibility-based rule to handle constraint for genetic algorithm where pair-wise solutions are compared using the following criteria:

- Between two feasible solutions, the one with the highest fitness values wins.
- If one solution is feasible and the other one is infeasible, the feasible solution wins.
- If both solutions are infeasible, the one with the lowest sum of constraint violation is preferred.

As a result, Deb [29] has introduced the superiority of feasible solutions selection procedure based on the idea that any individual in a constrained search space must first comply with

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