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Comparative analysis of evolutionary algorithms for the problem of parametric optimization of PID controllers

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Abstract

Six modern and promising evolutionary algorithms are described: genetic algorithm, differential evolution method, variational genetic algorithm, particle swarm optimization algorithm, bat-inspired method and firefly algorithm. For all algorithms brief description and main steps of receiving solution are given. In the experimental part all algorithms are compared by the effectiveness of solving the parametric optimization problem for PID controllers.

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Keywords: evolutionary algorithms; global optimization problem; genetic algorithm; differential evolution algorithm; variational genetic algorithm; particle swarm optimization; bat-inspired algorithm; fireflies algorithm.

1. Introduction

Global optimization problems are among the most frequently encountered in practice, and this trend is relevant to this day in the scientific community. Generally, global optimization problem includes choosing such parameters of a system that optimize certain its properties. When it comes to optimizing the function of the large number of variables, unrestricted on the whole set of solutions, the search for a solution of this problem by classical methods of global optimization requires a large amount of calculations which takes a significant time. Moreover, many of the methods impose restrictions on the target function as its differentiability which is not always possible in practice. Truly effective and convenient method of optimization have to find the true global extremum, regardless of the initial data, and the implementation and use of such method should be simple.

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Evolutionary algorithms were established as a good methods for solving the problems of global optimization of large dimensions. However, many scientists still say the lack of so-called mathematical basis in evolutionary algorithms.

Also class of modern and rapidly developing population algorithms are well suited for solving complex problems of global optimization. The effectiveness of modern population algorithms commensurate with the evolutionary algorithms, and the prospect of their use open up wide opportunities.

At the first the aim of this work is confirmation of the high efficiency of evolutionary and population algorithms for solving problems of global optimization and at the second - a comparison of the considered algorithms. The paper provides a brief description of the most popular evolutionary and population algorithms. Further it is proposed to compare algorithms among themselves. Finding the most effective algorithm of the considered is done by repeated analysis of solutions of the optimization problem for the closest approach to the values of quality criteria. All algorithms are compared while solving the task of finding optimal PID controller values of the automatic control system. Calculation results of the comparison is made on the tournament principle in which algorithm providing more approximate to the values of quality criteria receives the points, which are summed up at the end of each test run of all algorithms.

2. The class of evolutionary algorithms

Evolutionary algorithms – a wide class of algorithms based on the usage of the basic principles of the biological evolution theory, such as the selection of the fittest individuals, their mutation and the generation of descendants. This class of evolutionary algorithms includes genetic algorithms, differential evolution algorithms, evolutionary strategies and evolutionary programming, each of which has a large number of modifications.

2.1. Genetic algorithm

The most widely used and well discussed in the scientific papers is the class of genetic algorithms. The genetic algorithm is the first presented among the class of evolutionary algorithms. Wide acceptance and dissemination of genetic algorithms have become possible through the papers of John Holland in the 60-70 years of XX century[1,2].

J. Holland noted that the creation of the theory of genetic algorithms was inspired by biological processes of natural selection, heredity and variation in nature which were described in papers of Charles Darwin in 1859.

The scheme of the genetic algorithm is very similar to the evolutionary processes in nature:

Randomly creates an initial population of individuals that appear in the form of chromosomes. Further at each iteration fitness function $\varphi(s_i)$ of each individual is tested which determines the probability of survival of the individual.

At the next step – the selection step – some individuals are selected for crossover. There are a lot of different ways to select individuals, most of which use the principle of random selection with probability proportional to the value of the fitness function of the individual. In this approach it is possible that the most fitted individuals will not get into a new generation. To prevent such a situation it is advisable to use a principle of elite selection in which a given number b of individuals with high adaptability are guaranteed to be included in the next generation and the remaining individuals are included by the general selection rules.

The genetic operators crossover and mutation are applied to the selected individuals. During the crossover individuals-descendants are created by recombination of the chromosomes of individuals-parents. For this a randomly selected crossing point r is chosen at the range of the chromosome length and all bits to the right of this crossing point r in two chromosomes are being changed:

$$H_1 = \left(h_{1,1},\ h_{1,2},\cdots,\ h_{1,r-1},h_{1,r},\cdots,h_{1,|H|}\right) \Rightarrow H_1^{'} = \left(h_{1,1},\ h_{1,2},\cdots,\ h_{1,r-1},h_{2,r},\cdots,h_{2,|H|}\right)$$

$$H_2 = \left(h_{2,1},\ h_{2,2},\cdots,\ h_{2,r-1},h_{2,r},\cdots,h_{2,|H|}\right) \Rightarrow H_2^{'} = \left(h_{2,1},\ h_{2,2},\cdots,\ h_{2,r-1},h_{1,r},\cdots,h_{1,|H|}\right)$$