Comparison of some evolutionary algorithms for optimization of the path synthesis problem

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Abstract

The paper presents comparison of the results obtained in a mechanism synthesis by means of some selected evolutionary algorithms. The optimization problem considered in the paper as an example is the dimensional synthesis of the path generating four-bar mechanism. In order to solve this problem, three different artificial intelligence algorithms are employed in this study.

Keywords: four-bar mechanism, genetic algorithms, particle swarm optimization, forest optimization algorithms

1. Introduction

Synthesis is a very important part of mechanism and machine theory. In general there are two types of synthesis: type and dimensional synthesis. In the paper the evolutionary algorithms are employed to optimize the dimensional synthesis of mechanisms. The synthesis consists in searching for links dimensions, mechanism position and orientation in order that the mechanism satisfies prescribed functions with a given accuracy.

The applications of evolutionary algorithms in theory of mechanisms are still growing (see e.g. [1]). Probably the first work devoted to mechanism synthesis in which the genetic algorithm has been used was written by Fang [2]. Some authors applied also the artificial immune system algorithms [3] or the particle swarm optimization algorithm [4].

The purpose of the paper is to compare some selected evolutionary algorithms (one new and two commonly used algorithms) for optimization problems of mechanisms synthesis. As an example the dimensional synthesis of path generating four-bar mechanism is considered in the paper.

2. Artificial intelligence algorithms for optimization problems

Three different artificial intelligence algorithms are employed in this study to solve optimization problems in mechanism synthesis. The applied methods are: genetic algorithms, particle swarm optimization algorithms and forest optimization algorithms.

2.1. Genetic algorithms

The genetic algorithms (GA) are the oldest methods analysed in this study. These algorithms were inspired by a natural selection process [5-8]. In this algorithm each potential solution is so called chromosome and is represented by a sequence of binary values (0 and 1). Very important feature of these algorithms are genetic operators: crossover and mutation. The algorithms have been successfully applied in many optimization problems.

2.2. Particle swarm optimization algorithm

The particle swarm optimization algorithms (PSO) were proposed in 1995 by Kennedy and Eberhart [9]. The algorithms were motivated by movements of individuals in a bird flock or fish school. A potential solution in the method is called a particle.

2.3. Forest optimization algorithms

The method is quite new and it was proposed in 2014 by Ghaemi and Feizi-Derakhshi [10]. The forest optimization algorithms (FOA) are inspired by a process observed in nature allowing some trees to survive in the forests for many years. The algorithm consists of three main steps. The first one is local seeding of the trees, next step is the population limiting and the last step is the global seeding of the trees. The general block diagram of this method is also presented in Fig. 1.

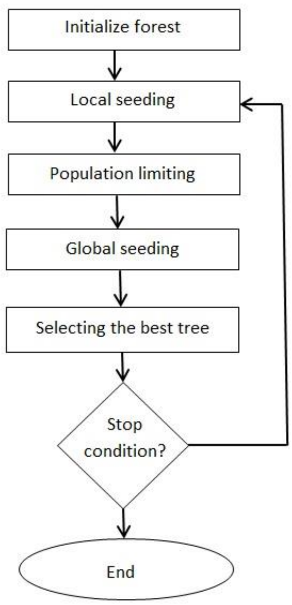

Figure 1: The block diagram of the FOA

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3. The four-bar mechanism

The four-bar mechanism consists of the input link, the coupler with the tracer point and the output link. Example of such a mechanism is depicted in Fig. 2.

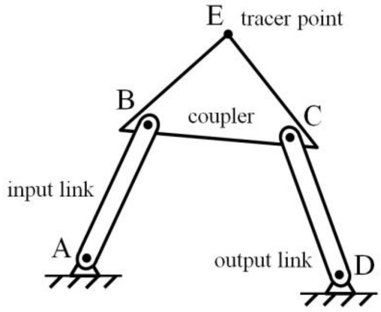

Figure 2: Four-bar mechanism

In this study synthesis of a path generating four-bar mechanism is considered.

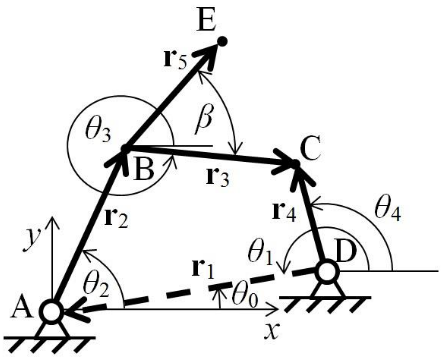

Figure 3: The vector loop in the four-bar mechanism

The vector loop equation takes the form

$$\mathbf{r}_1 + \mathbf{r}_2 + \mathbf{r}_3 - \mathbf{r}_4 = \mathbf{0}. \tag{1}$$

The angular position of the coupler is as follows

$$\theta_3 = 2\tan^{-1}\left(\frac{-G + \sqrt{G^2 - 4HF}}{2H}\right) + \theta_0, \tag{2}$$

where:

$$F = K_1 + (K_2 - 1)\cos(\theta_2 - \theta_0) + K_3, \tag{3}$$

$$G = -2\sin(\theta_2 - \theta_0), \tag{4}$$

$$H = \cos(\theta_2 - \theta_0) - K_1 + K_2\cos(\theta_2 - \theta_0) + K_3, \tag{5}$$

$$K_1 = \frac{r_1}{r_2},\ \ K_2 = \frac{r_1}{r_3},\ \ K_3 = \frac{r_4^2 - r_1^2 - r_2^2 - r_3^2}{2r_2 r_3}. \tag{6}$$

Thus the tracer point location is given by

$$r_{EX} = r_2\cos(\theta_2) + r_5\cos(\theta_3 + \beta) + x_0, \tag{7}$$

$$r_{EY} = r_2\sin(\theta_2) + r_5 c\sin(\theta_3 + \beta) + y_0. \tag{8}$$

The design variables in the considered problem are:

- dimensions of the mechanism (r_1, r_2, r_3, r_4, r_5, β),
- orientation – the ankle θ_0,
- location of the point A (x_0, y_0) in the global coordinate system,
- sequence of the input link angles θ_{2i} (i = 1,2,…,n).

4. Objective function and optimization constraints

The objective function is defined as

$$f = \sum_{i=1}^{n}\left[\left(R_{Xi} - r_{EX}(\theta_{2i})\right)^2 + \left(R_{Yi} - r_{EY}(\theta_{2i})\right)^2\right] + p, \tag{9}$$

where (R_{Xi}, R_{Yi}) for i = 1,2,…,n are prescribed locations of the tracer point, ($r_{EX}(\theta_{2i})$, $r_{EY}(\theta_{2i})$) for i = 1,2,…,n are the positions of the coupler point of the mechanism defined by means of an evaluated set of design variables, and p is the penalty function, which equals zero if all constrains are met and it takes a very high value if at least one of the constrains is not satisfied.

The following constrains are taken in the considered optimization problem:

- the Grashof's law – the sum of lengths of the shortest (s) and longest (l) links has to be smaller or equal to the sum of lengths of the two other link (p and q)

$$s + l \le p + q, \tag{10}$$

- sequence of the input link angles θ_{2i} of desired locations of the tracer point has to be sorted in increasing order,
- limits of the design variables.

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