Application of Particle Swarm Optimization for classical engineering problems

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Abstract— **In the design of mechanical elements, designers usually consider certain objectives that are related with cost, time, quality and reliability of product, depending on the requirements. In this paper, parametric optimization of spring design problem, pressure vessel design problem has been carried out using Particle Swarm Optimization (PSO for short). The results obtained using PSO are compared with the results reported by other researchers.**

Keywords-optimization, pso algorithm, spring, pressure vessel

I. INTRODUCTION

Metaheuristics are an impressive area of research, with extremely important improvements, and are used for solving intractable optimization problems. Major advances have been made since the first metaheuristic was proposed and numerous new algorithms are still being proposed every day. There is no doubt that the studies in this field will continue to develop in the near future. In the field of metaheuristics, there is a set of algorithms which draw inspiration from nature, so called biologically-inspired metaheuristic algorithms. The most famous biologically-inspired metaheuristic algorithms are: Differential evolution (DE), Ant Colony optimization (ACO), Grey Wolf Optimizer (GWO), Bat Algorithm (BA), Whale Optimization Algorithm (WOA), Grasshopper Optimization Algorithm (GOA).

In this paper, we will apply PSO for solving classical problems in engineering.

The first problem [1] consists of minimization of spring weight subject to constrains on minimum deflection, shear stress, surge frequency, limits on the outside diameter and design variables. The design variables are: coil diameter D, wire diameter d and number of active coils N.

The second problem is optimization of a pressure vessel, which consists of reducing costs of material, montage and welding costs. Four variables are defined for this problem: radius of shell, length of the shell, thickness of the shell and thickness of the dish end [2].

The pseudo code for this algorithm was written using Matlab R2018a software suite.

At the end, the results obtained by PSO algorithm are compared to the results previously obtained by other algorithms.

II. PARTICLE SWARM OPTIMIZATION

PSO algorithm was developed in 1995. by Eberhart and Kennedy [3]. It took little time for this algorithm to attract attention of many researchers, and is still used for solving engineering problems.

The phenomenon from which this algorithm draws inspiration is very interested. It is based on simulating the motion of a group of particles moving in solution space, where the position of a particle represents a solution of the problem. Since the algorithm is dealing with a group of solutions, it belongs to the class of metaheuristic algorithms that are called population-based (or p-based) metaheuristics. The whole of the particles is called population. By moving the particles their variables values change, and tracking, controlling, and directing these particles help them reach the optimum.

Characteristic variables that are necessary for the realization of this algorithm are position and speed. A particle's position in a given moment represents a potential solution, while only the current best position is memorized and leads the optimization process.

New solution is based on Equation (1).

$$X_{New,i} = X_{Old,i} + \upsilon_{New,i} \tag{1}$$

Having :

$$\upsilon_{New,i} = \omega \cdot \upsilon_{Old,i} + C_p \cdot r_p \left(X_{p,i} - X_{x,i} \right) + C_g \cdot r_g \left(X_{g,i} - X_{x,i} \right) \tag{2}$$

In Equation (2), ω represents particle inertia, while C_p and C_g represent acceleration factors. Acceleration factors are positive-valued constants which control the local influence for the given particle and the global direction for the given particle. Variables r_p i r_g are assigned random values between 0 and 1, and are used to vary search along the whole problem space. The variable X_{pi} represents the best position of a given particle, variable X_{gi} represents the best position for the whole population, while the variable X_{xi} represents the current position.

Value ω is calculated by using Equation (3).

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{Iteration_{\max}} \cdot Iteration \quad (3)$$

In Equation (3), ω_{max} and ω_{min} represent the initial and final values for inertia. The recommended values for these parameters are 0.9 and 0.4, respectively. The values for ω must therefore be in the range between 0 and 1. The values for C_p i C_g are adjusted according to researchers' experience and the literature, and their recommended values are 1.5 for both constants. There is much research that focus on examining the algorithm's efficiency with regards to the coefficients, with the fore mentioned value of 1.5 being but one of the many recommended values.

In order to demonstrate the workings of PSO algorithm, the crux of the algorithm, that is the motion of particles, is given in Fig. 1.

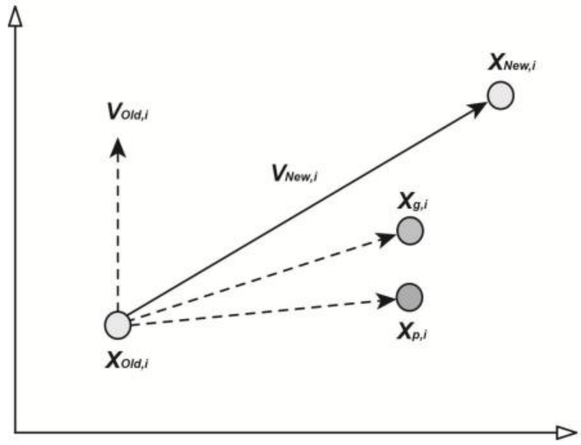

Fig. 1 Graphic representation of particle movement

This algorithm was applied to the practical optimization problems in engineering as well [4-6], most notably to the problems of structural optimization. The analysis of these problems was performed by using the standard PSO algorithm, as well as its modifications and hybrid algorithms.

Around 2010, the largest use for this algorithm was in the field of multicriterial optimization problems [7-10]. The Integrated Particle Swarm Optimization (IPSO for short) algorithm, and a hybrid of Genetic algorithm and Particle Swarm Optimization, called Genetic Algorithm Particle Swarm Optimization (GAPSO for short) were used for practical management engineering problems [11]. The literature mentioned in this paper represents only a small part of research literature focused on PSO algorithm.

Flow diagram for the PSO algorithm is shown in Fig 2.

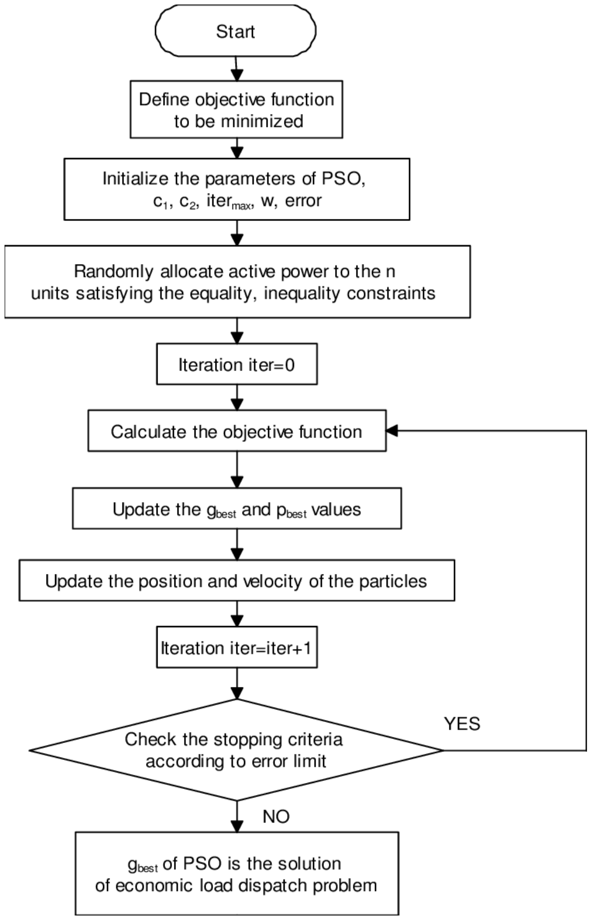

Figure 2. Flow diagram for PSO algorithm

III. EXPERIMENTAL ENGINEERING EXAMPLES FOR OPTIMIZATION

The main problem with these two examples is to find the minimum optimal solution which must satisfy a series of given constraints.

The optimization problem having only one objective function can be formulated in the following manner:

$$\begin{aligned} &\min/\max\ f(x), \\ &g_j(x) \le 0, \qquad j = 1,2,\ldots,J; \\ &h_k(x) = 0, \qquad k = 1,2,\ldots,K; \\ &x_i^G \ge x_i \ge x_i^D, \quad i = 1,2,\ldots,N. \end{aligned} \quad (4)$$

Where:

- $f(x)$ objective function
- $x = [x_1\ x_2 \ldots x_N]^T$ vector of problem variables
- $g_j(x)$ inequality-type constraints
- $h_k(x)$ equality-type constraints
- x_i^D lower bound for x_i
- x_i^G upper bound for x_i

This chapter will present certain examples of engineering problems, such as: optimization of helical spring and pressure vessel. The basis of the problem, the objective function, variable parameters that should be found as well as the constraints that should be respected will be shown.

The optimum design of helical spring problem is to minimize the volume of the spring (Fig 3) under four non-linear constraints.

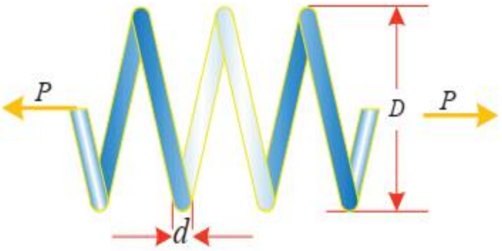

Figure 3. Helical spring design

Formally, the first problem can be expressed as minimization of the function $f(x) = (x_3 + 2)x_2x_1^2$, defined in [12], subject to the following constraints:

$$g_1(x) = 1 - \frac{x_2^3 x_3}{71785 x_1^4} \le 0; \quad (5)$$

$$g_2(x) = \frac{4x_2^2 - x_1x_2}{12566(x_2x_1^3 - x_1^4)} + \frac{1}{5108x_1^2} - 1 \le 0; \quad (6)$$

$$g_3(x) = 1 - \frac{140,45x_1}{x_2^2 x_3} \le 0; \quad (7)$$

$$g_4(x) = \frac{x_1 + x_2}{1,5} \le 0; \quad (8)$$

$$0,05 \le x_1 \le 2; \quad (9)$$

$$0,25 \le x_2 \le 1,3; \quad (10)$$

$$2 \le x_3 \le 15; \quad (11)$$

A detailed presentation of the results obtained by the PSO algorithm and comparison of several best results obtained by using other algorithms are given in Table 1. In [12], Differential Evolution Algorithm is used, paper [13] uses Genetic Algorithm, paper [14] uses Modified Ant Colony Optimization, while paper [15] uses Water Cycle Optimization.

TABLE 1. COMPARISON OF RESULTS BETWEEN PSO AND OTHER ALGORITHMS FOR HELICAL SPRING

Objective function	Abderazek [12]	Coello [13]	Grkovic [14]	Eskandar [15]	**PSO**
f(x)	0.01266	0.01268	0.01265	0.01266	**0.01268**

Based on results shown in Table 1, a conclusion can be drawn that the objective function having the value of 0.01268, that is obtained using the PSO algorithm, is close to other values found in literature.

In Figure 4, a convergence diagram for the problem of helical spring optimization is given.

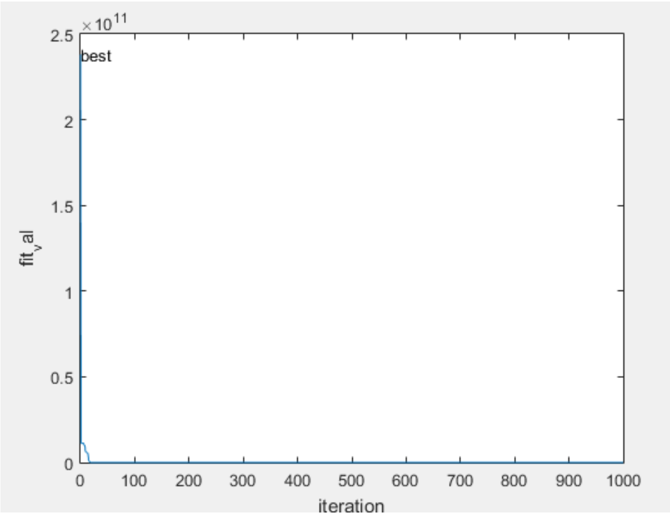

Figure 4. Convergence graph for the best solution for helical spring design

The pressure vessel problem (Figure 5) must be designed for minimum total fabrication cost subject to four constraints.

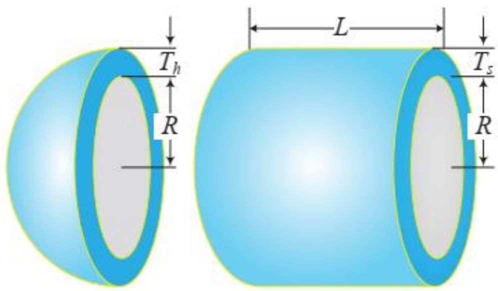

Figure 5. Cylindrical pressure vessel design

Objective function to be minimized, as defined in [12]:

$$f(x) = 0,6224x_1x_3x_4 + 1,7781x_2x_3^2 + 3,1661x_1^2x_4 + 19,84x_1^2x_3 \quad (12)$$

$$g_1(x) = -x_1 + 0,0193x_3 \leq 0; \quad (13)$$

$$g_2(x) = -x_2 + 0,00954x_3 \leq 0; \quad (14)$$

$$g_3(x) = -\pi x_3^2 x_4 - \frac{4}{3}\pi x_3^3 + 1296000 \leq 0; \quad (15)$$

$$g_4(x) = x_4 - 240 \leq 0; \quad (16)$$

In Table 2, a comparison of results for design of a pressure vessel optimization problem are shown. In [12], Differential Evolution Algorithm is used, while paper [13] uses Genetic Algorithm, and paper [16] uses Grasshopper Optimization Algorithm.

TABLE 2. COMPARISON OF RESULTS BETWEEN PSO AND OTHER ALGORITHMS FOR PRESSURE VESSEL

Objective function	Abderazek [12]	Coello [13]	Jovanovic [16]	**PSO**
f(x)	6059.714	6288.74	7665.12	**5885.33**

PSO algorithm achieved better result than Abderazek, Coello and Jovanovic.

In Figure 5, a convergence diagram for the problem of pressure vessel optimization is given.

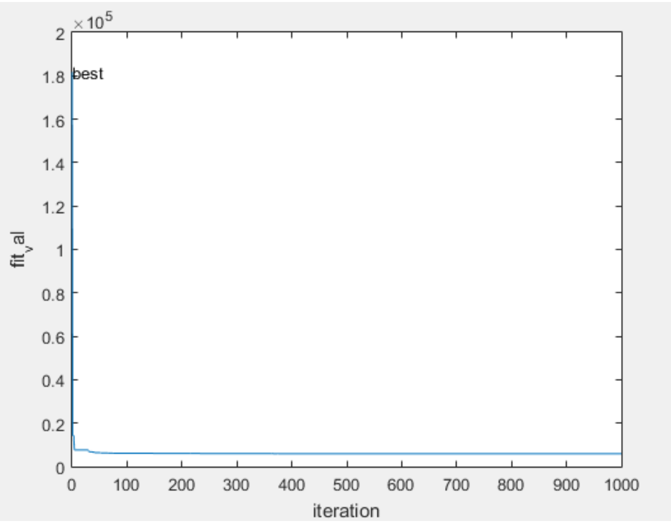

Figure 6. Convergence graph for the best solution for pressure vessel design

IV. CONCLUSION

This paper describes the PSO algorithm, as well as its application in few engineering problems. The mentioned engineering problems of helical spring and pressure vessel design are given in detail, using mathematical formulation and figures, and the results are given in tables.

Based on results given in Table 1, a conclusion can be drawn that the objective function obtained using PSO algorithm is close to other values found in literature.

In the case of pressure vessel, using PSO algorithm gives better results than those obtained by using GOA, GA and NAMDE algorithms.

Therefore, solving these problems using the new optimization technique presented in this paper provides an important opportunity for researchers to compare the performances of their new methods using complex mechanical engineering design optimization problems.

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