Optimal Design of Welded beam structure using hybrid Meta-heuristic Algorithm

REZKI Ines
Institute of Optics and Precision Mechanics
Applied Precision Mechanics Laboratory
Setif, Algeria
rezkiines1993@gmail.com

DJEDDOU Ferhat
Institute of Optics and Precision Mechanics
Applied Precision Mechanics Laboratory
Setif, Algeria
djeddouferhat@yahoo.fr

HAMmOUDA Abdellatif
Institute of Optics and Precision Mechanics
QUERE Laboratory
Setif, Algeria
a_hammouda1@yahoo.fr

***Abstract*— To overcome the limitation of some of the metaheuristic optimization algorithm engineer tries to developed new algorithm or modified the older one by making combination between metaheuristic algorithm that are already exist this process is called hybridization and it's become an important tool to solve many real-life optimization applications in the industry.**

This paper proposes a hybrid algorithm based on the combination between differential evolution algorithm and particle swarm optimization algorithm .the algorithm was tested on well knowing mechanical benchmark and the results are compared to other optimization algorithm from literature.

***Keywords*— differential evolution; particle swarm; Hybridization; Mechanical system; meta-heuristic**

I. INTRODUCTION

Engineering is a profession whereby principles of nature are applied to build useful objects. The design of industrial component is often dependent on the parameter of the design itself. A well designed system demands the choice of parameters on which its design is based. To solve real life problems engineer tend to use numerical methods called optimization approach such as evolution algorithm and swarm intelligence.

Both algorithm are widely used in multiple problems and they show a big efficacy for solve constrained and unconstrained problem. Despite of their advantage these algorithms have limitation in certain problem. In order to improve their performance a number of modifications have been suggested in literature, one of them being the hybridization of the two algorithms. Hybridization is a trend observed in many studies on meta-heuristics. It allows taking advantage of the cumulative advantages of different meta-heuristics. Some hybrid versions of DE and PSO include Swagatam Das et al. [1] proposed a hybridization of PSO and DE for continuous optimization problems. Xiaoping [2] introduced an algorithm by making balance between DE and PSO parameters where the population was generated either by DE or PSO according to the algorithms parameters. José Garcia [3] proposed to use the scheme employed in DE as a mechanism to adjust the velocity of particles in PSO algorithm.

One of the most well known benchmark in mechanics is the design of welded beam problem for minimum cost. Many researchers have been done on this problem Ragsdell and Phillips in [4] have presented optimal design parameters for a class of welded beam structures using Geometric programming approach and compared their results with those produced by the methods contained in a software package called Opti-Sep. This problem was also solved by Deb [5] using a simple genetic algorithm with binary representation, and a traditional penalty function. Carlos A. Coello Coello [6] have introduced a new GA-based technique that uses coevolution to adjust automatically the weight factors of a penalty function to find optimum solution of welded beam design their result showed better solution compared to [4] and [5]. A differential evolution approach based on a co-evolution mechanism, named CDE, is proposed by Fu-zhuo Huang, Ling Wang and Qie He [7] to solve the welded beam design problem using a special penalty function to handle the constraints. Qie He, Ling Wang [8] have presented a novel constraint-handling technique called co-evolutionary particle swarm optimization CPSO based on incorporating a co-evolution model into PSO in which a part of the swarm are used for evolving suitable penalty factors. Tapabrata Ray and K. M. Liew [9] have introduced an optimization algorithm that is based on a society and civilization model and used a novel no dominance scheme to handle constraint. In order to solve numerical optimization problems R M Rizkallah [10] applied a new algorithm called SCA-OPI which include a sine–cosine algorithm (SCA) integrated with orthogonal parallel information the algorithm some engineering applications. This paper presented the Hybridization of differential evolution and particle swarm optimization algorithm, called DEPSO, the new algorithm is applied on a well knowing design and the results were compared to other algorithm taking from literature.

II. BASIC OF DEPSO ALGORITHM

A. *Differentiel Evolution*

DE algorithm is a stochastic optimization method minimizing an objective function that can model the problem's objectives while incorporating constraints. As an advanced computing technique, differential evolution was first proposed by Price and Storn in 1995.This technique includes three important operations: mutation, crossover and selection, and it utilize the three operators to evolve from randomly generated initial population to final individual solution. Mutation and crossover are used to generate new vectors (trial vectors), and selection is then used to determine whether the new generated vectors can survive the next generation .The algorithm mainly has three advantages; finding the true global minimum regardless of the initial parameter values, fast convergence, and using a few control parameters Being simple, fast, easy to use, very easily adaptable for integer and discrete optimization, quite effective in nonlinear constraint optimization including penalty functions and useful for optimizing multi-modal search spaces are the other important features of DE.[11,12]

B. Particle swarm optimization

Particle Swarm Optimization (PSO) is a nature inspired metaheuristic method. This method was first introduced by Kennedy and Eberhart in 1995 [13] .it incorporates swarming behaviors observed in flocks of birds, schools of fish, or swarms of bees, and even human social behavior, from which the idea is emerged. PSO is a population-based optimization tool, which could be implemented and applied easily to solve various function optimization problems, or he problems that can be transformed to function optimization problems. As an algorithm, the main strength of PSO is its fast convergence, which compares favorably with many global optimization algorithms [14].

C. DEPSO

Despite the big advantages of differential evolution and PSO algorithms in many domains, each of these algorithms has its own weak point, to overcome these shortcomings new variations must be made on the algorithm. The DEPSO algorithm combine the ability to maintain the diversity of population and to explore the search space from DE algorithm and the mechanism to memory the previous steps and to use global information about the search space from PSO.This hybridization decreases the probabilities to trap in local optimum and increase the speed convergence of the algorithm.

The pseudo code of the Hybrid DE and PSO (DEPSO) Algorithm is:

Input: the initial values of control parameters: NP, G_{max}, Var, Cr and F.
Step1: / / Initialization
For i =1 to NP population size do
Generate an initial population X_{ij}
Evaluate the initial population using penalty function to handle constraints
Step2: // Generation Loop
For g=1 to G_{max} do
For j=1 to Var (dimension) do
Generate the trial vector // r_1, r_2, r_3 are Selected randomly such us that $r_1 \neq r_2 \neq r_3$

$$V_{i,j}^{g+1} = X_{r_1}^{g} + F(X_{r_2}^{g} - X_{r_3}^{g})$$

Select $j_{rand} \in$ Var
If (rand () < CR or j = jrand) // rand () denotes a uniformly distributed random
number between 0 and 1//

$$U_{i,j}^{g+1} = V_{i,j}^{g+1}$$

Else

$$U_{i,j}^{g+1} = X_{i,j}^{g}$$

End if
Evaluate the trial vector using penalty function to handle constraints
If $f(U_{i,j}^{g+1}) < f(X_{i,j}^{g})$ then

$$X_{i,j}^{g+1} = U_{i,j}^{g+1}$$

Else
PSO activated
Find a new particle using PSO mechanism
End if
End for
End for.
Output: the best individual with the smallest objective function value in the population

In the DEPSO algorithm the PSO mechanism is integrated in the DE in the phase of selection and it activate only when the solution found by DE algorithm didn't satisfy the condition. The algorithm has only few control parameters and it is simple, fast, and easy to use.

III. BENCHMARK PROBLEM AND RESULTS

A. Experimental settings

Like the other métaheuristic algorithm the DEPSO has a few control parameter to adjust, the population size NP and the maximum number of generations allowed for each algorithm Gmax presented in TABLE 1, are the input parameters for the DEPSO algorithm .

TABLE I. INPUT PARAMETER FOR THE DEPSO ALGORITHM

Input paramètres	Population size	Gmax
DE	50	500
PSO	30	500

In this section a mechanical constrained design benchmark optimization problem from the literature is used to test the performance of DEPSO algorithm .Many papers were published to solve this problem using different other optimization algorithm .now the DEPSO algorithm is applied to the same problem and comparisons are made .one of the major problem of constrained problem is how to deal with violation of constraint. Deb's heuristic constraint handling method (Deb's 2000) based on penalty function is used in this problem. The details on the design benchmark problem are given in the following section.

B. Design of Welded Beam

The objective is to design a welded beam for minimum cost. There are four design variables height of weld (h), length of weld (L), height of beam (t) and width of beam (b) as shown in Fig.1. Design vector can be defined as x=(x1, x2, x3, x4). Design is subjected to the constraints on shear stress (s), bending stress in the beam (r), buckling load on the bar (P_c), end deflection of the beam (d) and side constraints. This problem is solved by many researchers by using different optimization methods [15].

The problem can be stated as follows:

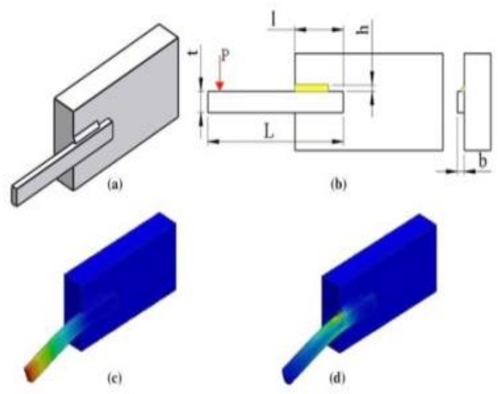

Fig.1. **a** 3D view of the welded beam, **b** 2D view of the welded beam, **c** displacement heat map, **d** stress heat map [16].

$$f(x) = 1.10471x_1^2x_2 + 0.04811x_3x_4(14 + x_2) \quad (1)$$

Subject to:

$$g_1(x) = \tau(x) - \tau_{max} \leq 0 \quad (2)$$

$$g_2(x) = \sigma(x) - \sigma_{max} \leq 0 \quad (3)$$

$$g_3(x) = x_1 - x_4 \leq 0 \quad (4)$$

$$g_4(x) = 1.10471x_1^2x_2 + 0.04811x_3x_4(14 + x_2) - 5.0 \leq 0 \quad (5)$$

$$g_5(x) = 0.125 - x_1 \leq 0 \quad (6)$$

$$g_6(x) = \delta(x) - \delta_{max} \leq 0 \quad (7)$$

$$g_7(x) = P - P_c(x) \leq 0 \quad (8)$$

Where:

$$\tau(x) = \sqrt{(\tau')^2 + 2\tau'\tau''\frac{x_2}{2R} + (\tau')^2} \quad (9)$$

$$\tau' = \frac{P}{\sqrt{2}x_1x_2} \quad (10)$$

$$\tau'' = \frac{MR}{J} \quad (11)$$

$$M = P(L + \frac{x_2}{2}) \quad (12)$$

$$R = \frac{x_2{}^2}{4} + (\frac{x_1+x_2}{2})^2 \quad (13)$$

$$J = 2\left[\sqrt{2}x_1x_2\left[\frac{x_2{}^2}{12} + (\frac{x_1+x_3}{2})^2\right]\right] \quad (14)$$

$$\sigma(x) = \frac{6PL}{x_4x_3{}^2} \quad (15)$$

$$\delta(x) = \frac{4PL^3}{Ex_4x_3{}^3} \quad (16)$$

$$P_c(x) = \frac{4{,}013E\sqrt{\frac{x_3^2x_4^6}{36}}}{L^2}\left(1 - \frac{x_3}{2L}\sqrt{\frac{E}{4G}}\right) \quad (17)$$

Where:

$P = 6000lb$, $L = 14in.$, $E = 30 \times 10^6 psi$, $G = 12 \times 10^6 psi$, $\tau_{max} = 13{,}600\, psi$, $\sigma_{max} = 30{,}000 psi$, $\delta_{max} = 0.25 in.$ $0.1 \leq x_1 \leq 2$, $0.1 \leq x_2 \leq 10$, $0.1 \leq x_3 \leq 10$, $0.1 \leq x_4 \leq 2$

τmax is the design shear stress of weld, τ is the weld shear stress, σmax is the design normal stress for beam material,σ is the maximum beam bending stress, P_c is the bar buckling load, δ is the beam end deflection, E is the modulus of elasticity for the beam material, and G is the modulus of rigidity for the beam material.

IV. RUSULTS AND DISCUSSION

This problem is a minimization problem that involves four continuous design variables with seven constraints. the statical results on the constrained benchmark problem and the convergence of best result from DEPSO algorithm for the welded beam design problem is presented in Fig.2 and comparison with other metaheuristic in the next section.

TABLE II. PARAMETER AND OBJECTIVE VALUES OF THE BEST SOLUTIONS OBTAINED FOR SPEED REDUCER PROBLEM

variable	x_1	x_2	x_2	x_2	F(x)
CPSO[8]	0.202369	3.544214	9.048210	0.205723	1.728024
GA3(Coello 2000) [17]	0.208800	3.420500	8.997500	0.21000	1.748309
GA4 [18]	0.205986	3.471328	9.020224	0.206480	1.728226
CDE[7]	0.203137	3.542998	9.033498	0.20617	1.733462
FFA[19]	0.185944	4.105960	9.198642	0.210641	1.844646
SCA[20]	0.185860	3.771335	8.963635	0.210707	1.758722
LSCA[20]	0.175914	3.874794	9.051892	0.208883	1.758463
DEPSO	**0.20573**	**3.4705**	**9.0366**	**0.20573**	**1.7249**

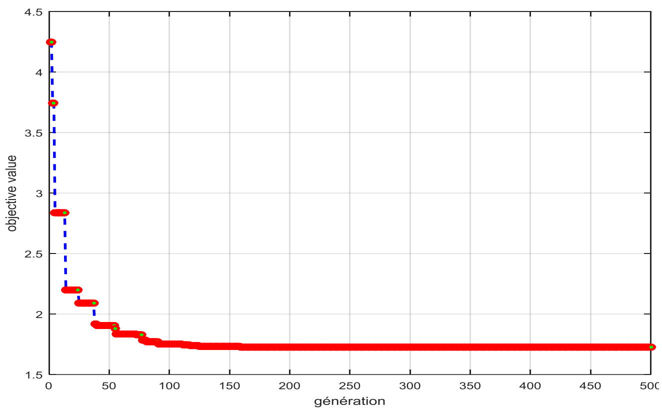

Fig.2. Evolution of best mean results obtained by DEPSO for welded beam design

The solution given by DEPSO algorithm for the proposed problem of welded beam design show better results than other algorithm in term of quality of final solution and the simulation results of the best solution show that the algorithm can achieve the optimal solution for the given problem.

V. CONCLUSION

In this paper hybrid algorithm called DEPSO is proposed which combines DE and PSO mechanism and its performance is validated on benchmark from real life problems. Numerical results show that DE-PSO outperformed other optimization algorithm and it is more effective in obtaining better solution.

REFERENCES

[1] S. Das, A.Abraham, and A. Konar,” Particle swarm optimization and differential evolution algorithms: Technical analysis, applications and hybridization perspectives”,In Advances of Computational Intelligence in Industrial Systems ,2008, pp 1-38.

[2] X.Yu, J. Cao, H. Shan, Z. Li ,and J. Guo , “An Adaptive Hybrid Algorithm Based on Particle Swarm Optimization and Differential Evolution for Global Optimization” , Hindawi Publishing Corporation the Scientific World Journal, vol. 2014, Article ID 215472, 2014, pp. 1-16.

[3] J. G. Nieto, E. Alba, and A. Javier,” Noiseless Functions Black-Box Optimization: Evaluation of a Hybrid Particle Swarm with Differential Operators”, In Genetic and GECCO’09, July 8–12, 2009, MontréalQuébec, Canada, pp 2231-2237.

[4] K. M. Ragsdell and D.T.Phillips,”optimal design of a class of welded structures using geometrique programming», journal of engineering for industry, Augest 1976, pp1021-1025.

[5] K. Deb, “Optimal Design of a Welded Beam via Genetic Algorithms”, AIAA Journal, 29(11), 2013{2015, November 1991.

[6] A.Carlos and C. Ceollo,”uses of a self adaptive penalty approach for engineering optimization problem”, 8 June 1999, pp 1-26.

[7] F.Z. Huang, L. Wang, and Q. He, “an effective coevolutionary differential evolution for constrained optimization», Applied mathematics and computation 186, 2007, pp 340-356.

[8] Q. He and L. Wang, “an effective coevolutionary particle swarm optimization for constrained engineering design problem”, engineering application of artificial Intelligence 20, 2007, pp 89-99.

[9] T. Ray and K. M. Liew,”Society and Civilization: An Optimization Algorithm Based on the Simulation of Social Behavior”, IEEE Transactions on evolutionary computation, VOL. 7, NO4, 8August 2003, pp 386-396.

[10] R.M. Rizk Allah,” An improved sine–cosine algorithm based on orthogonal parallel information for global optimization”, Methodologies and application”, 03 July 2018, pp 1-27.

[11] D. Zou, H. Liu, L. Gao, and S. Li,”A novel modified differential evolution algorithm for constrained optimization problems”,

Computers and Mathematics with Applications 61, 2011, pp 1608–1623.

[12] D.Karaboga and S. Okdem, a Simple and Global Optimization Algorithm for Engineering Problems: Differential Evolution Algorithm, Turk J Elec Engin, VOL.12, NO.1, 2004, pp 53-60.

[13] S. Asta and A. Şima Uyar ," A Novel Particle Swarm Optimization Algorithm",10th international conference on artificial evolution at Anger,France,2011,pp 1-12

[14] S. S. Aote, M. M. Raghuwanshi and L. Malik," A Brief Review on Particle Swarm Optimization: Limitations & Future Directions", International Journal of Computer Science Engineering (IJCSE), ISSN : 2319-7323, Vol. 2 No.05, September 2013 ,pp196-200.

[15] R. Rao Venkata and J. Savsani Vimal , Mechanical Design Optimization Using Advanced Optimization Techniques.spring series in advanced manufacturing, Springer Verlag London , 2012, pp88-90.

[16] S. K. Pourazari and S. K. Pourazary,"An efficient hybrid algorithm based on water cycle and Moth-Flame optimization algorithm for solving numerical and constrained engineering optimization problems», Methodologies and Application,28 October 2017,pp 1-24.

[17] C.A.C.Coello,"Use of a self-adaptive penalty approach for engineering optimization problems". Computers in Industry 41, 2000, pp 113–127.

[18] C.A.C.Coello, " Theoretical and numerical constraint handling techniques used with evolutionary algorithms: a survey of the state of the art", Computer Methods in Applied Mechanics and Engineering 191 (11/12), 2002, pp 1245–1287.

[19] A.A. El-Sawy, E.M. Zaki and R.M. Rizk-Allah, "A novel hybrid ant colony optimization and firefly algorithm for solving constrained engineering design problems". J Nat Sci Math 6(1), 2013, pp 1–22.

[20] S. Mirjalili," SCA: a sine cosine algorithm for solving optimization problems", Knowl-Based Syst 96, 2016, pp120–133.