Solving the Problem of Pressure Vessel with Constraint Conditions through Marine Predators Algorithm

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Abstract: With the development of artificial intelligence technology, various intelligent algorithms are becoming more and more mature. Swarm intelligent algorithm performs well among many algorithms. Optimization problems have been permeating into all aspects of life, and solving the condition optimization problem with constraints is a very important aspect. This paper adopts the newly proposed Marine Predators Algorithm in recent years. The original algorithm is improved by adding constraints. Optimization of pressure vessel problem using Marine predator optimization algorithm. The four variables of shell thickness, head thickness, inner radius and cylindrical section length are optimized on the premise that the pressure vessel is qualified. The variables are iterated to find the optimal solution. In order to show the excellent performance of the Marine Predators Algorithm, compared with other excellent algorithms, it has excellent performance in both convergence speed and stability.

Keywords: Marine Predators Algorithm, Pressure vessel, Optimization problem

1. Introduction

In recent years, various intelligent algorithms have been proposed instead of traditional optimization algorithms and have been widely used in optimization problems with the development of artificial intelligence technology. One type of intelligent algorithm is swarm intelligent algorithm that simulates various natural phenomena in daily life and biological behaviors in nature. [1] This kind of algorithm transforms the engineering optimization problem into the function optimization problem and establishes the objective function to seek the optimal solution. In this paper, the Marine Predators Algorithm (MPA) [2] is used as the research algorithm to solve the pressure vessel design problem [3] in engineering problems by using the group intelligent algorithm. Engineering problems are difficult to solve because they have complex objective functions and a large number of constraints. This paper establishes a reasonable mathematical model, iterates the variables, and seeks an optimal solution with high accuracy.

2. Marine Predators Algorithm

The Marine Predators Algorithm is a kind of group intelligence algorithm, which was proposed in 2020 as a simple and efficient algorithm. Its inspiration comes from the theory of Marine life survival, simulating the behavior of predators in the ocean. The algorithm has few parameters, simple configuration, easy to implement and high accuracy. Because of its excellent properties, it has been used by various scholars to solve more problems. [4-5] Although there are many ocean predators, they still have problems of unbalanced development and exploration capacity and unstable convergence speed. Therefore, according to their own needs, relevant researchers proposed variants of the Marine Predators Algorithm and used the variants of the Marine predator to solve practical problems. [6-11]

The Marine Predators Algorithm is divided into four stages: initialization stage, optimization scheme stage, FADs effect, eddy current and ocean memory. Initialize predators and elites in the first stage. The prey position is randomly initialized within the search space to start the optimization process. The optimization phase is divided into three stages, and there are specific iteration stages and iterations for each stage of predator and prey. Lévy flight and Brownian motion random walk strategies at different stages:

At high speed or when the prey is moving faster than the predator:

$$\begin{aligned} \overrightarrow{stepsize}_i &= \vec{R}_B \otimes (\overrightarrow{Elite}_i - \vec{R}_B \otimes \overrightarrow{Prey}_i) \qquad i = 1, \dots, n \\ \overrightarrow{Prey}_i &= \overrightarrow{Prey}_i + P.\vec{R} \otimes \overrightarrow{stepsize}_i \end{aligned} \tag{1}$$

When the unit speed ratio or when the predator and prey are moving at nearly the same speed:

$$\overrightarrow{stepsize_i} = \vec{R}_L \otimes (\overrightarrow{Elite_i} - \vec{R}_L \otimes \overrightarrow{Prey_i}) \qquad i = 1, \dots, n/2$$
$$\overrightarrow{Prey_i} = \overrightarrow{Prey_i} + P.\vec{R} \otimes \overrightarrow{stepsize_i} \tag{2}$$

At a low speed ratio or when the predator is moving faster than the prey:

$$\overrightarrow{stepsize_i} = \vec{R}_L \otimes (\vec{R}_L \otimes \overrightarrow{Elite_i} - \overrightarrow{Prey_i}) \qquad i = 1, \dots, n$$
$$\overrightarrow{Prey_i} = \overrightarrow{Elite_i} + P.CF \otimes \overrightarrow{stepsize_i} \tag{3}$$

$\vec{R}_L$ and $\vec{R}_B$ are random vectors of Lévy distribution and Brownian motion, respectively. P=0.5. $CF = (1 - \frac{Iter}{Max\_Iter})^{(2\frac{Iter}{Max\_Iter})}$. The symbol $\otimes$ represents the multiplication of the corresponding elements of two matrices.

The third stage is FADs effect and eddy current stage. Predators will move around the FADs. Therefore, as a local optimal, it considers a longer step size to avoid local optimality.

$$\overrightarrow{Prey_i} = \begin{cases} \overrightarrow{Prey_i} + CF[\vec{X}_{\min} + \vec{R} \otimes (\vec{X}_{\max} - \vec{X}_{\min})] \otimes \vec{U} & r \le FADs \\ \overrightarrow{Prey_i} + [FADs(1-r) + r](\overrightarrow{Prey_{r1}} - \overrightarrow{Prey_{r2}}) & r \ge FADs \end{cases} \tag{4}$$

FADs=0.2. r is the random number vector between the uniform interval [0,1]. $\vec{X}_{\max}$ and $\vec{X}_{\min}$ are the upper and lower bounds. The final stage is Marine memory, in which the predators in the ocean are compared with elite individuals based on the memory of successful hunting points. This stage simulates the situation in which a predator returns to a prey-rich area and successfully hunts.

3. Pressure vessel design problems

Pressure vessel design research is an important and complex engineering field, involving many key issues and challenges. Common research directions include structural optimization, material selection, fatigue life prediction and safety analysis and optimization algorithm application. Constraint optimization is the way of presenting most practical engineering application optimization problems. The main goal of solving the engineering optimization problem of high-constraint pressure vessel design is to manufacture a qualified pressure vessel at the lowest cost.

3.1 Problem modeling

This problem requires the determination of the following four design variables: shell thickness x_1, head thickness x_2, inner radius x_3, and the length of the cylindrical section ignoring the head x_4. This engineering problem is transformed into a minimization problem. Under the premise of finding four variables under four constraints, the minimum value $f(X)$ is satisfied. The mathematical model of pressure vessel design is:

$$\begin{aligned} &\min f(X) = 0.622 x_1 x_3 x_4 + 1.778 x_2 x_3^2 + 3.166 x_1^2 x_4 + 19.84 x_1^2 x_3, \\ &s.t.\ g_1(X) = -x_1 + 0.0193 x_3 \le 0, \\ &\quad g_2(X) = -x_2 + 0.00954 x_3 \le 0, \\ &\quad g_3(X) = -\pi x_3^2 x_4 - \frac{4}{3}\pi x_3^3 + 1296000 \le 0, \\ &\quad g_4(X) = x_4 - 240 \le 0. \end{aligned} \tag{5}$$

3.2 Optimization algorithm selection

In order to verify the practicability of the Marine Predators Algorithm, the pressure vessel optimization problem is selected for experiments. In order to measure the performance of the Marine Predators Algorithm, the Marine Predators Algorithm is compared with classical particle swarm optimization algorithm (PSO), sine-cosine algorithm (SCA), whale optimization algorithm (WOA) and gray Wolf algorithm (GWO) proposed in recent years.

3.3 Problem solving

In the comparison experiment, the upper limits of the four variables were set to 99, 99, 200, and 200 respectively. Set downlines to 0, 0, 10, and 10 respectively. The Number of search agents is 50 and the maximum number of iterations is 2000.

Each algorithm was independently run 30 times. Collect the optimal value, average value, standard difference and other data of each algorithm optimization result. All the results are summarized in the following table:

Table 1. Comparison results of different algorithms

Algorithms	Optimization result			The optimal value of the variable			
	Optimal value	Mean value	Standard deviation	x_1	x_2	x_3	x_4
MPA	5.89E+03	5.89E+03	2.30E-12	0.77817	0.38465	40.3196	200
PSO	6.02E+03	6.75E+03	2.72E+02	0.85151	0.420901	44.1196	153.1041
SCA	6.08E+03	6.66E+03	5.29E+02	0.84516	0.46151	43.2822	164.2593
WOA	6.18E+03	7.19E+03	5.33E+02	0.89817	0.64302	46.1865	131.8042
GWO	5.89E+03	5.89E+03	7.13E+00	0.78526	0.38897	40.6849	195.0174

As can be seen from Table 1, each algorithm has optimized the four parameters of pressure vessel to a certain extent. However, there are some differences in stability, convergence speed and accuracy. Compared with other algorithms, Marine Predators Algorithm can reach a better optimal value in each iteration. Although the scale of other algorithms is the same, the minimum problem reaches the optimal value and performs the best. The average value of the Marine Predators Algorithm is relatively stable, indicating that the algorithm is very stable. The algorithm all show good performance in exploring and developing modules. The standard deviation of the algorithm is low in 30 independent iterations, reaching 10^{-12}. It is much different from other algorithms in magnitude and has high convergence accuracy. It is stable when the optimal solution can be reached in each case. The optimal value of each algorithm variable is also shown in the table, which has certain reference value in practical industrial problems. It can be effectively used to solve the problem of manufacturing pressure vessels and maximize industrial benefits.

Using the number of iterations as the x-axis and the value of fitness as the y-axis. To make the image more intuitive, the y-axis is taken as its logarithm, and part of the graph is cropped as shown in Figure 1. From the figure, it can be intuitively seen that the Marine Predators Algorithm converges faster compared to other algorithms, with a more precise convergence value, enabling the optimization problem to minimize its objective function.

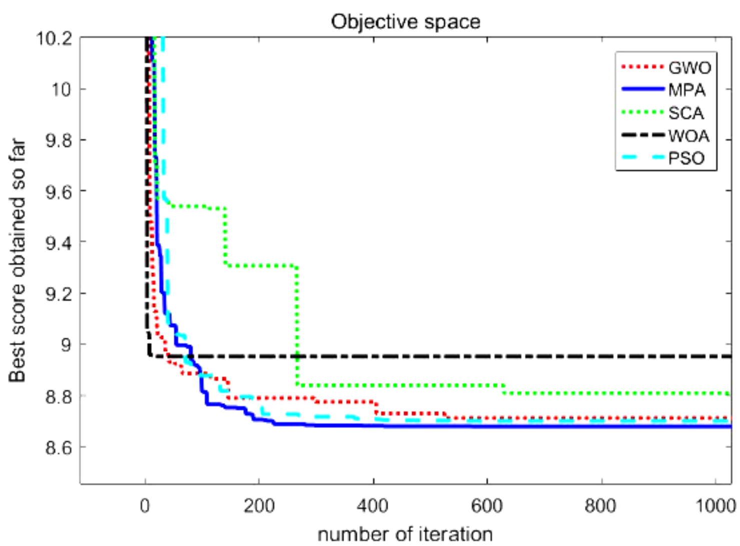

Figure 1. Iterative curves of each algorithm

4. Conclusions

The Marine Predators Algorithm has performed excellently on multiple benchmark functions, whether they are unimodal or multimodal. The Marine Predators Algorithm converges quickly and with high precision, capable of escaping local optima to find global optimal values. Therefore, this paper employs the innovative Marine Predators Algorithm to solve a classic problem in industry: the pressure vessel problem. The Marine Predator problem is improved to address constrained target optimization issues, minimizing the objective function under all four constraints. In experiments, the Marine Predators

Algorithm outperforms both classical algorithms and other novel algorithms, demonstrating excellent performance in both exploration and development. It exhibits outstanding performance with low standard deviation, showing remarkable stability. The constrained Marine Predators Algorithm does not get trapped in local optima and finds global optimal solutions for the four independent variables. This has significant reference value in industry. It can help factories save materials, producing qualified pressure vessels at the lowest cost, ensuring material savings and maximizing factory profits.

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