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EVALUATING THE COATI OPTIMIZATION ALGORITHM IN THE ANALYSIS OF 2D/3D TRUSS STRUCTURES

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Abstract

In this article, damage to 2D/3D truss structures is identified using the Coati Optimization Algorithm (COA), a metaheuristic technique. The fundamental idea of COA was to imitate two of the coatis' natural behaviors: (i) hunting and attacking iguanas, and (ii) escaping predators. Moreover, by using natural frequencies from finite element analysis for truss structure to set up the objective function, the final results prove the effectiveness of this algorithm in solving real-world structures.

Introduction

A variety of natural phenomena, animal, insect, and bird behaviors, physical laws, biological sciences, human activities, game rules, and any other evolution-based process serve as inspiration for the concepts used in the building of metaheuristic algorithms. Based on the main source of inspiration used in their creation, metaheuristic algorithms can be divided into five categories: (i) swarm-based, (ii) evolutionary-based, (iii) physics-based, (iv) game-based, and (v) human-based algorithms. The behavior of animals, insects, birds, and other living creatures in nature, as well as natural swarming occurrences, has served as inspiration for the development of swarm-based algorithms. These techniques include the Coati Optimization Algorithm (COA), which is based on modeling two natural behaviors of coatis [1, 2]; the Marine Predators Algorithm (MPA), which is inspired by the searching behavior of marine predators and their Brownian and Lévy movements in prey hunting [3]; the Gray Wolf Optimization Algorithm (GWO), which is inspired by the social life and hunting strategy of gray wolves [4]; the Whale Optimization Algorithm (WOA), which is inspired by the bubble-net hunting strategy of humpback whales [5]; and so on. Natural selection law, random operators, biology, and genetics modeling concepts have all been used to construct evolutionary-based algorithms. Among the most popular evolutionary algorithms are Genetic Algorithm (GA) [6] and Differential Evolution (DE) [7], which are based on Darwin's theory of evolution, natural selection, modeling the reproductive process, and the application of random operators of selection, crossover, and mutation. The introduction of physics-based algorithms is predicated on the mathematical modeling of numerous physics-related phenomena, ideas, laws, and forces. One of the most well-known physics-based algorithms is the Simulated Annealing (SA) algorithm, which was applied in [8]. Inspired by gravitational force, algorithms like GSA [9] have been developed through mathematical modeling of physical forces. Game-based algorithms have been created by mimicking player behavior and the environment and regulations governing different games. The Volleyball Premier League

(VPL) approach is inspired by how players and coaches behave during volleyball matches [10]. The Football Game-Based Optimizer (FGBO) was created using mathematical modeling of football league team managers' choices and player behavior [11]. Mathematical models of human behaviors, activities, and social and individual interactions have served as the foundation for the development of human-based algorithms. One of the most popular human-based algorithms, TLBO [12], was created using mathematical modeling of a classroom learning environment and teacher-student interactions with the goal of raising knowledge levels. The Following Optimization Algorithm (FOA) is based on a mathematical simulation of how a community leader affects the advancement of individuals [13].

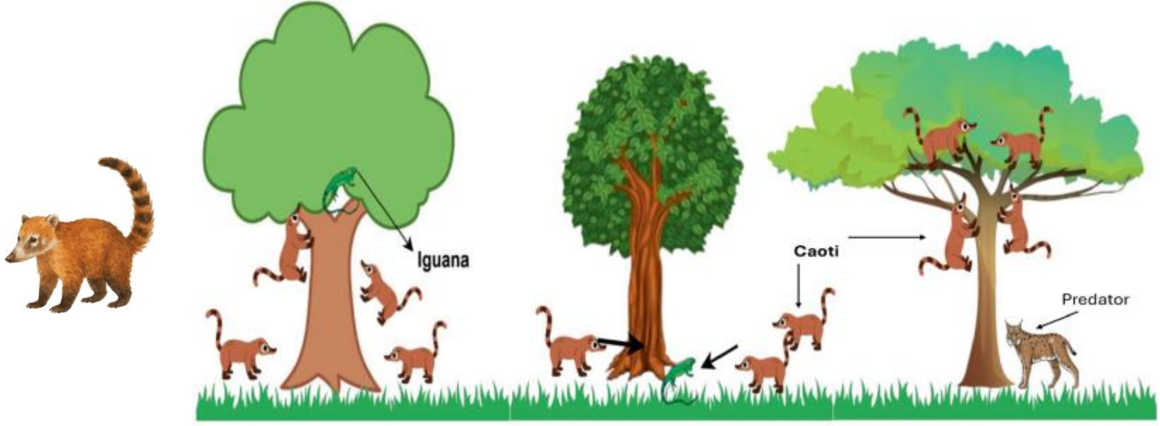


Fig. 1 Coati and daily activities, [2]

In this article, damage to truss structures is predicted using the Coati Optimization Algorithm (COA), which was inspired by the behavior of coati in life, as in Figure 1. It would be remiss not to mention some information about finding the natural frequencies of a structural system based on finite element analysis, as in the documents [14-15].

The following sections of this article are as follows: The algorithm of COA is represented in Part 2. The results are shown in Part 3, and some comments are made in the last section.

The Algorithm of COA

Two natural behaviors of coatis include (*i*) coatis' strategy when attacking iguanas and (*ii*) coatis' escape strategy from predators. The algorithm below explicitly represents the two phases (exploration and exploitation) in which the COA population is updated.

Step 1: Input the problem information

Step 2: Set the number of iterations T and the number of coatis N. Initialization of the positions of all coatis by Eq. (1) and evaluation of the objective function

$$\begin{aligned} &X_i:\quad x_{ij} = lb_j + random \cdot \left(ub_j - lb_j \right) \\ &i = 1,\ldots,N;\quad j = 1,\ldots,m \end{aligned} \tag{1}$$

Step 3: For *t*=1:T, update location of the iguana related to the best member of the population

Step 4: Exploration phase:

for *i*=1:N/2

Determine new position of the *i*th coati

$$\begin{aligned} &X_i^{P1}: \quad x_{ij}^{P1} = x_{ij} + random \cdot \left(Iguana_j - I \cdot x_{ij} \right) \\ &i = 1, \ldots, N/2; \quad j = 1, \ldots, m \end{aligned} \tag{2}$$

Update position of the *i*th coati

$$X_i = \begin{cases} X_i^{P1}, & F_i^{P1} < F_i \\ X_i, & else \end{cases} \tag{3}$$

end

for *i*=(N/2+1):N

Calculate position of the iguana

$$Iguana^G: \quad Iguana_j^G = lb_j + random \cdot \left(ub_j - lb_j \right) \tag{4}$$

Determine new position of the *i*th coati

$$\begin{aligned} &X_i^{P1}: \quad x_{ij}^{P1} = \begin{cases} x_{ij} + random \cdot \left(Iguana_j^G - I \cdot x_{ij} \right), & F_{Iguana^G} < F_i \\ x_{ij} + random \cdot \left(x_{ij} - Iguana_j^G \right), & else \end{cases} \\ &i = N/2+1, \ldots, N; \quad j = 1, \ldots, m \end{aligned} \tag{5}$$

Update position of the *i*th coati by Eq. (3)

end

Step 5: Exploitation phase: calculate the local bounds for variables

$$lb_j^{local} = \frac{lb_j}{t}, \quad ub_j^{local} = \frac{ub_j}{t}, \quad t = 1, \ldots, T \tag{6}$$

for *i*=1:N

Determine new position of the *i*th coati

$$\begin{aligned} &X_i^{P2}: \quad x_{ij}^{P2} = x_{ij} + (1 - 2random) \cdot \left(lb_j^{local} + random \cdot \left(ub_j^{local} - lb_j^{local} \right) \right) \\ &i = 1, \ldots, N; \quad j = 1, \ldots, m \end{aligned} \tag{7}$$

Update position of the *i*th coati

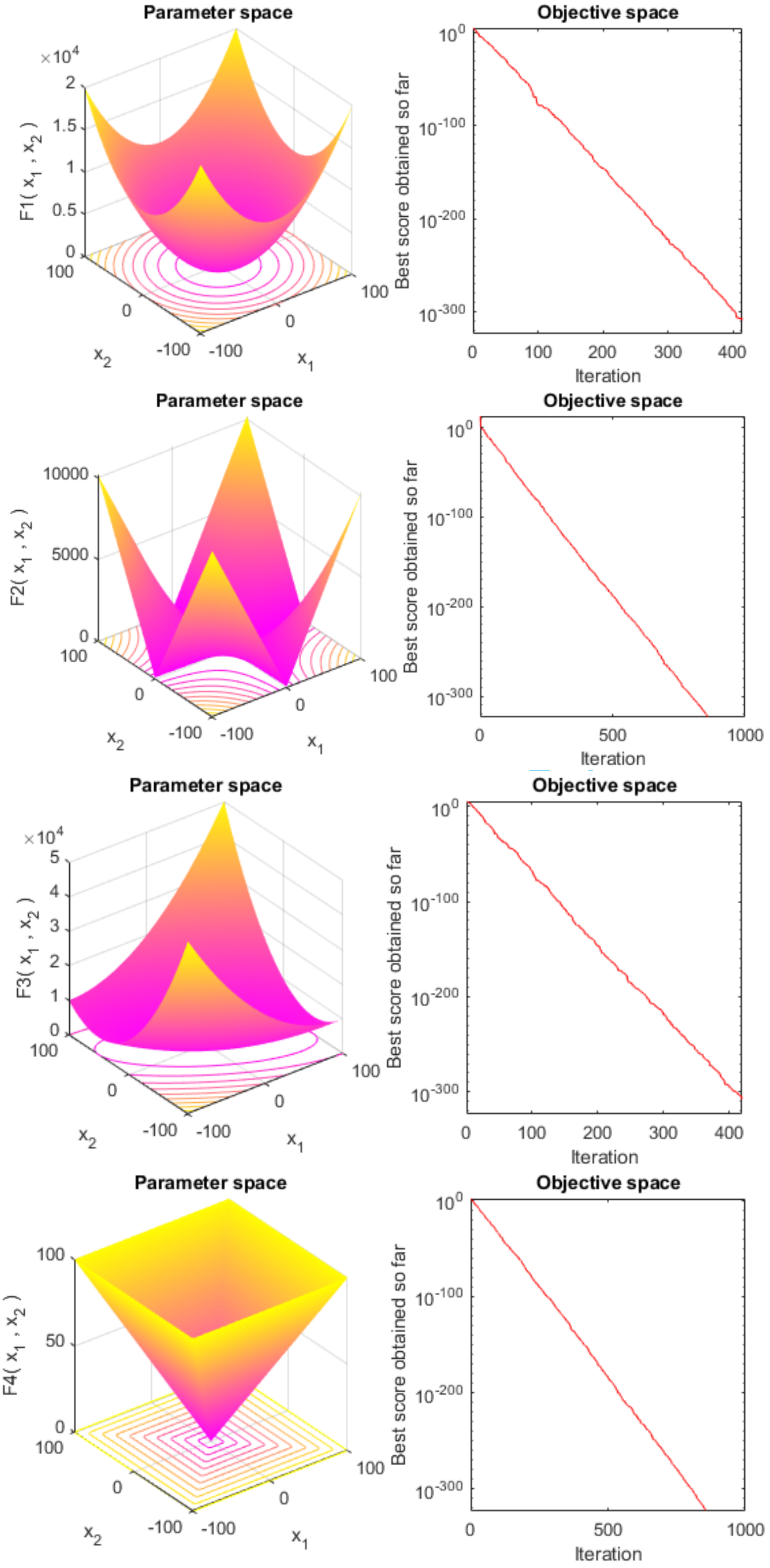
$$X_i = \begin{cases} X_i^{P2}, & F_i^{P2} < F_i \\ X_i, & else \end{cases} \tag{8}$$

end

Step 6: Save the best solution and end for *t*

Step 7: Output of the best obtained solution.

Here, *random* is a random real number in the interval [0, 1], X_i^{P1}, X_i^{P2} are the new position determined for the *i*th coati with two phases, x_{ij}^{P1}, x_{ij}^{P2} are its jth dimension, and F_i^{P1}, F_i^{P2} are its objective function values. Lower bound and upper bound are indicated by lb and ub, respectively. Figure 2 displays the qualitative analysis results of the COA approach in resolving a number of typical optimization problems. Details and comprehensive information on these functions are described in [4-5].


Parameter space
Objective space
$\times 10^4$
F1(x_1 , x_2)
x_1
x_2
Best score obtained so far
Iteration
Parameter space
Objective space
F2(x_1 , x_2)
x_1
x_2
Best score obtained so far
Iteration
Parameter space
Objective space
$\times 10^4$
F3(x_1 , x_2)
x_1
x_2
Best score obtained so far
Iteration
Parameter space
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F4(x_1 , x_2)
x_1
x_2
Best score obtained so far
Iteration

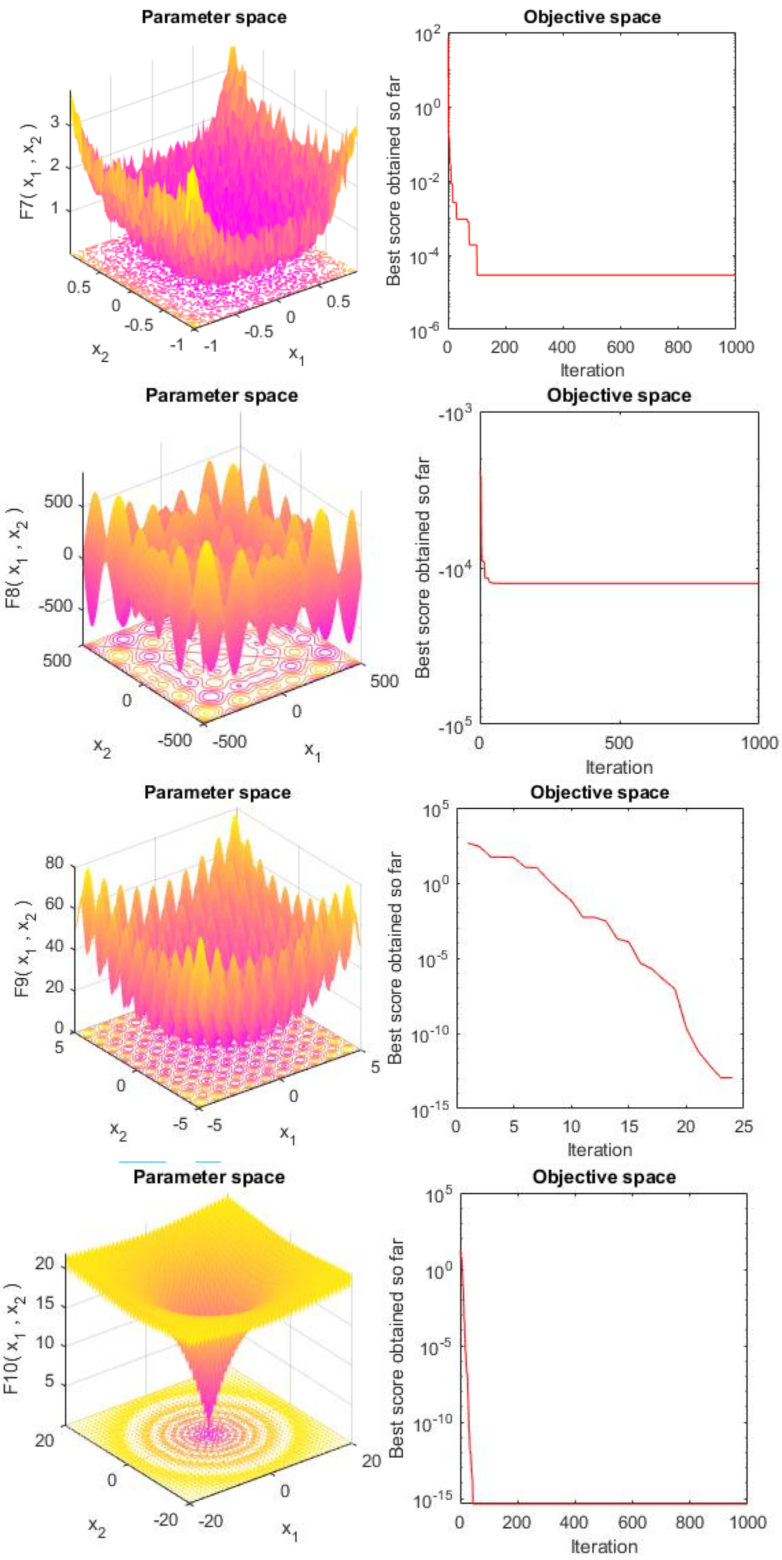


Fig. 2 Qualitative analysis

Results

In this section two 2D/3D truss structures with 15 bars and 19 bars are considered as in Figures 3 and Tables 1 & 2.

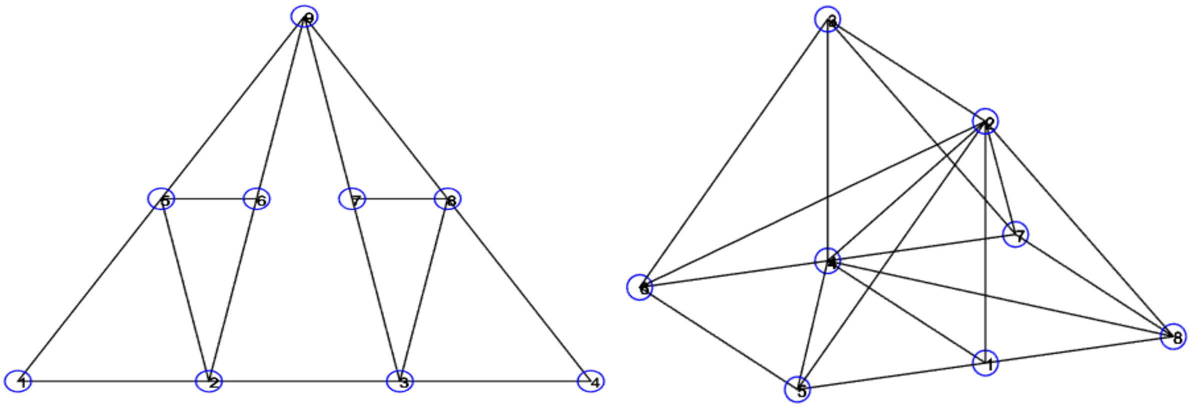
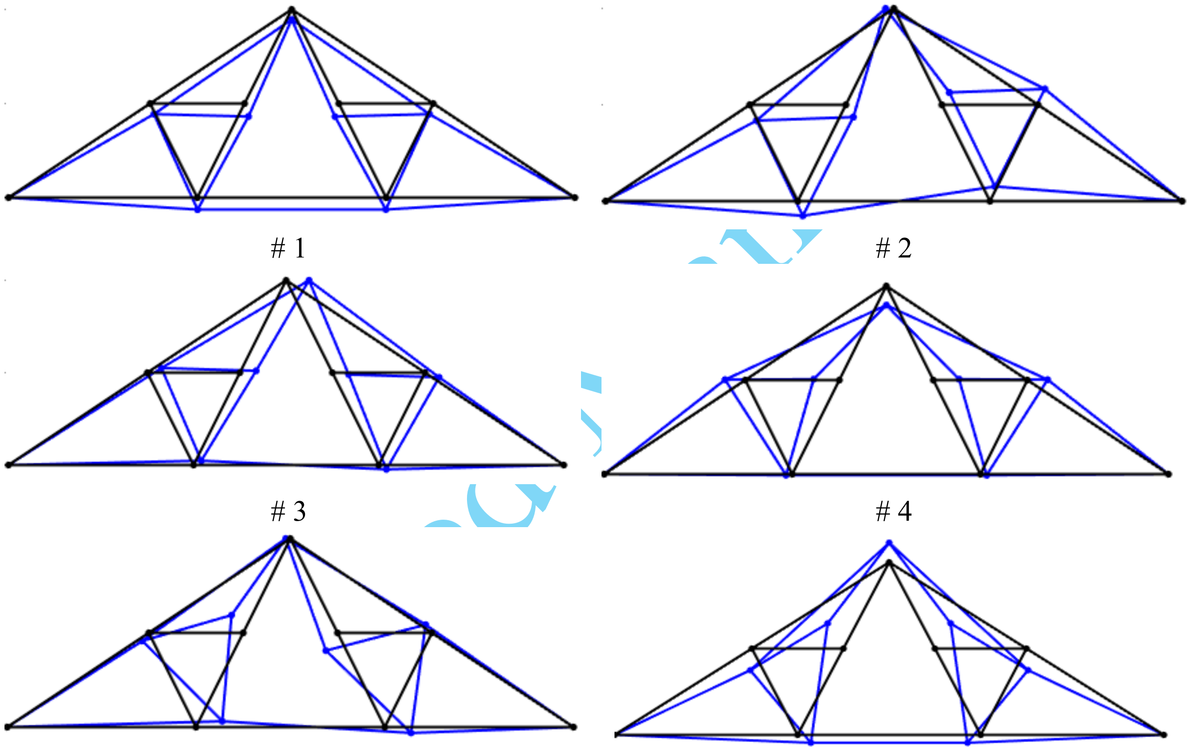


Fig. 3 Two structures: 15-bar 2D truss & 19-bar 3D truss



1

2

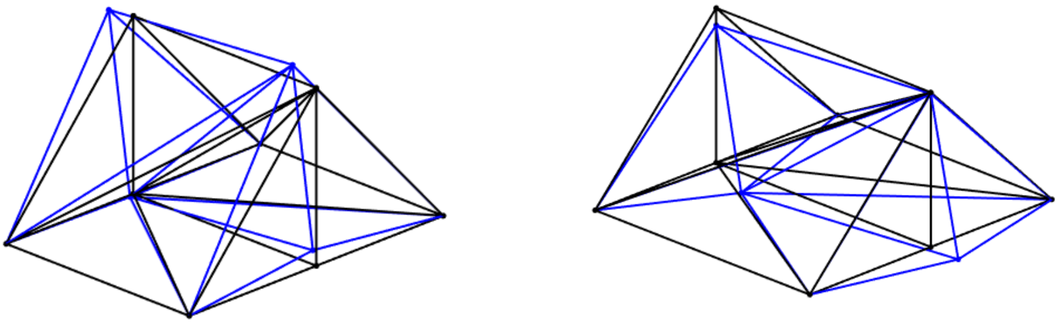
3

4

5

6

Fig. 4 The first six mode shapes of 15-bar 2D truss



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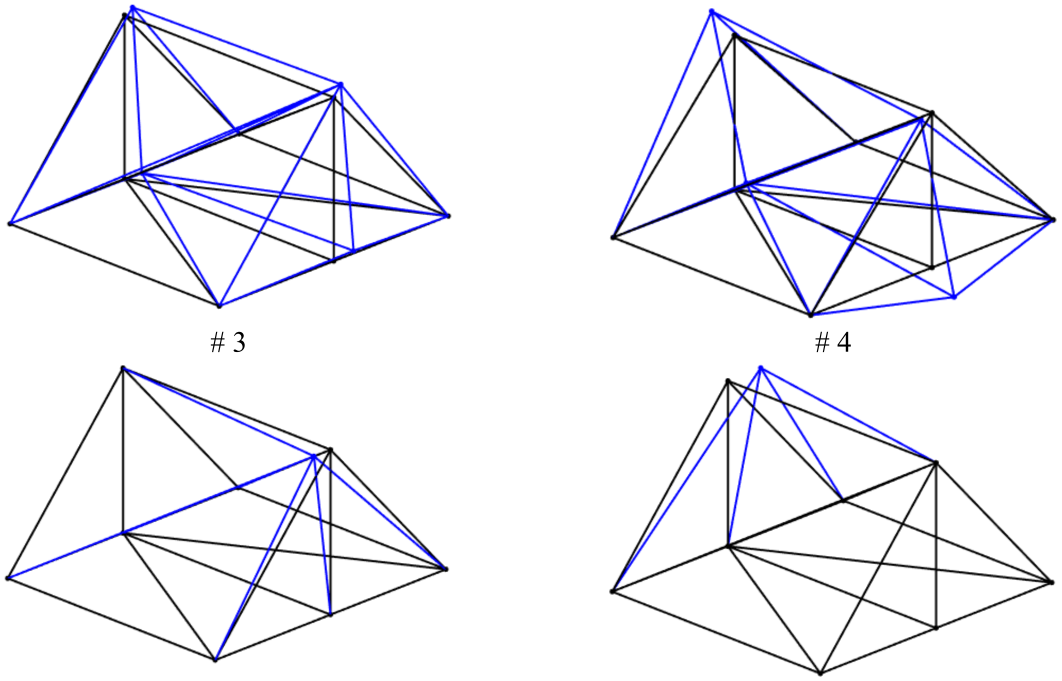
2



3

4

5

6

Fig. 5 The first six mode shapes of 19-bar 3D struss

Table 1. Properties of bar

A	*E*	*ρ*
0,000707 m^2	205e9 N/m^2	7833 kg/m^3

Table 2. Coordinates of nodes

15-bar 2D truss			19-bar 3D truss			
Node	x(m)	y(m)	Node	x(m)	y(m)	z(m)
1	*0*	*0*	1	*6*	*0*	*0*
2	*2*	*0*	2	*6*	*0*	*3,6*
3	*4*	*0*	3	*6*	*3,6*	*3,6*
4	*6*	*0*	4	*6*	*3,6*	*0*
5	*1,5*	*1*	5	*0*	*0*	*0*
6	*2,5*	*1*	6	*0*	*3,6*	*0*
7	*3,5*	*1*	7	*12*	*3,6*	*0*
8	*4,5*	*1*	8	*12*	*0*	*0*
9	*3*	*2*				

Table 3. Nodes at both ends of bar

15-bar 2D truss						19-bar 3D truss					
Bar	Nodes		Bar	Nodes		Bar	Nodes		Bar	Nodes	
1	*1*	*2*	11	*7*	*8*	1	*1*	*2*	11	*1*	*8*
2	*2*	*3*	12	*5*	*9*	2	*2*	*3*	12	*2*	*5*
3	*3*	*4*	13	*6*	*9*	3	*3*	*4*	13	*2*	*7*
4	*1*	*5*	14	*7*	*9*	4	*1*	*4*	14	*3*	*7*
5	*2*	*5*	15	*8*	*9*	5	*2*	*4*	15	*3*	*6*
6	*2*	*6*				6	*1*	*5*	16	*2*	*6*
7	*3*	*7*				7	*5*	*6*	17	*2*	*8*
8	*3*	*8*				8	*4*	*6*	18	*4*	*8*
9	*4*	*8*				9	*4*	*7*	19	*4*	*5*
10	*5*	*6*				10	*7*	*8*			

The difference in natural frequencies between the finite element model and actual measurements is known as an objective function. Thereby, the severity and location of damage will be predicted. Eq. (9) illustrates the definition of damages where a reduction in the member's modulus of elasticity is essential:

$$E_b = (1-\varsigma)E, \quad 0 \le \varsigma \le 1 \tag{9}$$

in which ς is the variable showing the damage severity of each bar. By minimizing the following objective function, it is therefore simple to determine the location and severity of the damage(s):

$$OB = \sqrt{\sum_{i=1}^{6}\left(f_i^a - f_i^{fe}\right)^2 / \left(f_i^a\right)^2} \tag{10}$$

(*a*) and (*fe*) denote the "*actual*" and "*finite element*" while 6 is the number of frequencies taken into consideration. The first six mode shapes of 15-bar and 19-bar truss constructions are shown in Figures 4 and 5.

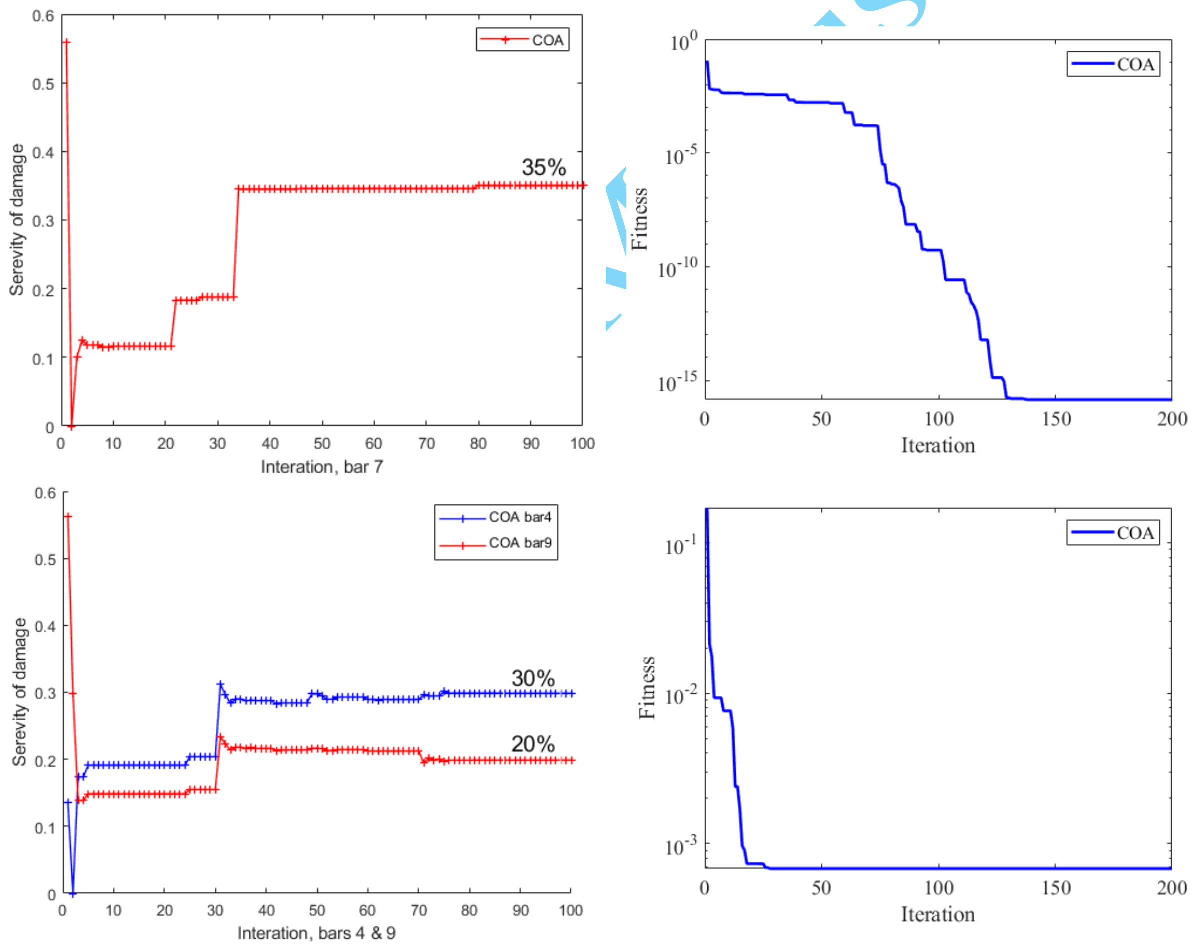


Fig. 6 The convergence for the damage situations of 16-bar 2D truss

Table 4. The damage situations of 15-bar 2D truss

Situations	Damage bar(s)	Severity of damage
The first situation	Bar 7	35%
The second situation	Bar 4	30%
	Bar 9	20%

Table 5. The damage situations of 19-bar 3D truss

Situations	Damage bar(s)	Severity of damage
The first situation	Bar 12	35%
The second situation	Bar 3	45%
	Bar 13	25%

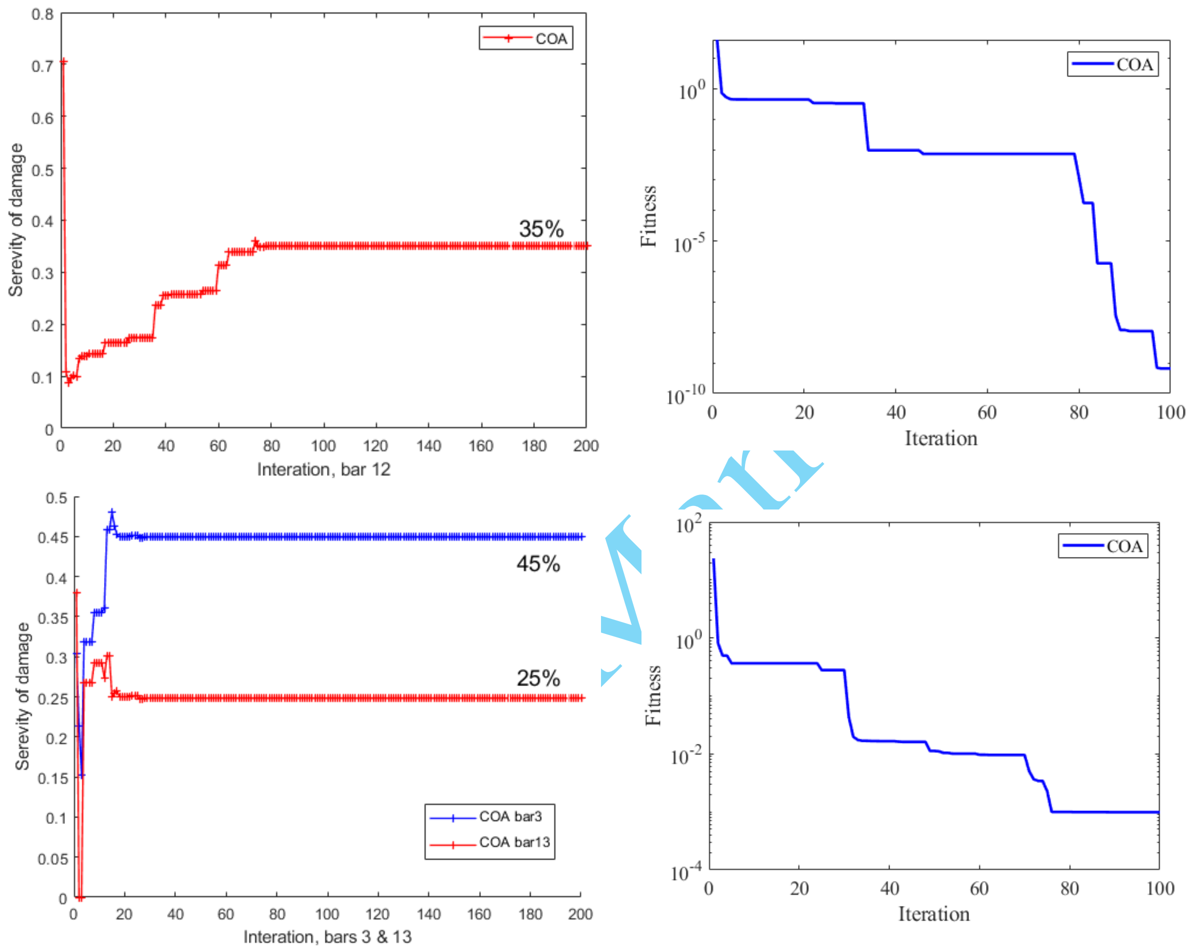


Fig. 7 The convergence for the damage situations of 21-bar 3D truss

To confirm the accuracy, some damage situations are given in Tables 4 and 5. The results, which are shown in Figures 6 to 7, demonstrate that COA produces the anticipated results for damage structure prediction. Furthermore, it is clear that the COA only needs roughly 100 iterations to produce the intended results.

Conclusion

This article describes how to detect damage in 2D/3D trusses using the Coati Optimization Algorithm (COA). The performance of this algorithm is tested in a variety of situations, ranging from straightforward to intricate. The results show how well this COA forecasts the location and magnitude of damage.

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Declaration of Conflicting Interests

The author declares no potential conflicts of interest with respect to the research and publication of this article.

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