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1 Introduction to the benchmark

In the Otimização Não-linear em Engenharia course, the 2024 benchmark focuses on the structural optimization of a ten-bar truss. The primary goal of this benchmark is to minimize the mass of the structure while maintaining mechanical integrity and adhering to structural balance and material elasticity constraints.

The problem is divided into two main optimization approaches, the first one is a sizing optimization approach focuses on identifying the optimal cross-sectional area for each of the ten bars that make up the truss; the second one is a shape optimization which involves modifying the positions of the structure's nodes [1].

The algorithm used to solve the problem is the Butterfly Optimization Algorithm (BOA).

2 Implementation

The programming language used for implementing the problem and the BOA algorithm is Python, chosen for its simplicity yet efficiency.

As the name suggests, the Butterfly Optimization Algorithm is inspired by butterfly behavior, where they use their sense of smell to find food or locate the best mate even over long distances, attracted by emitted fragrances [2].

Based on these behaviors, the algorithm initially generates a population of butterflies with random positions. Subsequently, it evaluates the intensity I of each butterfly's fragrance, considering "intensity" as the value of the objective function. Then, the best butterfly found is selected, and for each butterfly, two actions can be taken: move towards the position of the best one or explore other areas of the search space. The algorithm continues until a stop criterion is met.

The flowchart of the algorithm is depicted in Figure 1.

It should be noted that, for solving this particular type of problem, in addition to the basic algorithm parameters, an additional parameter indicating the presence of fixed nodes has been added. This parameter helps the algorithm recognize that the problem is one of shape optimization. After adjusting the positions of the butterflies, the positions of the fixed nodes are restored to their original ones.

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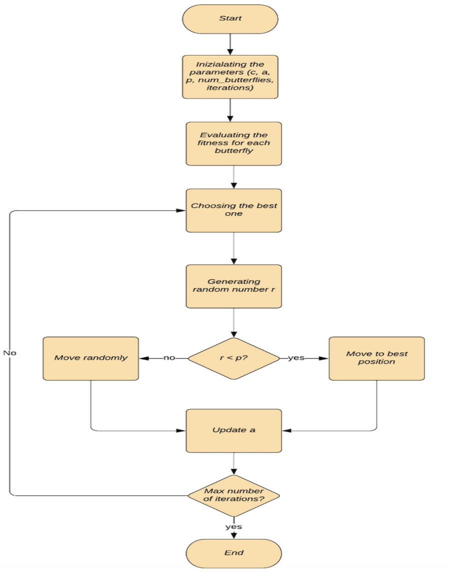

Figure 1. Flow chart diagram Butterfly Optimization Algorithm.

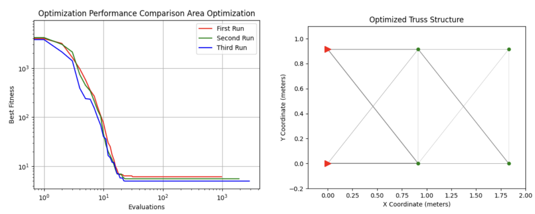

Figure 2. (a) Objective Function with Respect to the number of evaluation (b) Truss Bars Area

The initial parameters are: the power exponent which represent the absorption of the fragrance, a; the probability of moving towards the best butterfly, p; the number of individuals; the number of iterations and, finally, c will determine the speed convergence of the algorithm.

3 Results

After the optimization process, that was executed three times, the results shown in table 1 were obtained (only the best solution out of the three is reported). To obtain this results the following parameter were used: $a = 0.0001$ with a maximum value of 0.9, 5000 iterations, 150 butterflies, $p = 0.6$ and $c = 0.4$.

In Figure 2 and Figure 3, the results for the two formulations of the optimization problem are shown. More precisely in Figure 2.a the graph shows how the

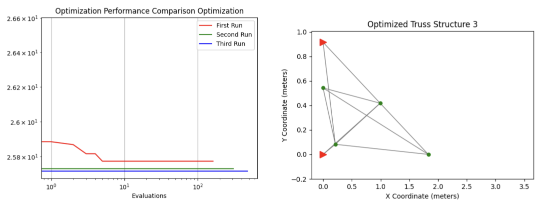

Figure 3. (a) Objective Function with Respect to the number of evaluation (b) Truss Shape

Table 1. Best solution of the optimization process

Variables	Solution	Objective function
Areas	[9.59887154e-05 4.50828800e-05 1.42410053e-04 5.62216119e-05 2.51525175e-05 1.96350000e-05 1.13908942e-04 4.65445885e-05 9.87115087e-05 2.69912308e-05]	4.993
Coordinates	[0.21315303 0.08228084 0 0.54247848 0.99271003 0.41770429]	25.718

objective function varies with an increasing number of evaluations. A typical trend to is the decreasing value of the objective function, indicating that the algorithm is finding lighter and more optimal structural configurations as it progresses through the iterations; in Figure 2.b are shown the optimized areas of the truss bars at the end of the optimization process. The specific values of the areas, as reported in the results, demonstrate a variation in the sizing of the bars to achieve an optimal structural configuration that minimizes mass while maintaining desired performance.

Similar to Figure 2.a, the Figure 3.a, shows a decreasing objective function, but specifically for the optimization of the truss shape. The Figure 3.b represents the final configuration of the truss, highlighting how the optimization has altered the position of the nodes to achieve an optimal shape. The coordinates mentioned in the results of the document reflect these changes and their impact on the objective function.

However, it is important to note that as a metaheuristic, BOA does not guarantee the finding of the global optimum. The solutions provided by the algorithm are sub-optimal but are usually sufficiently close to the best possible solution to be of practical use.

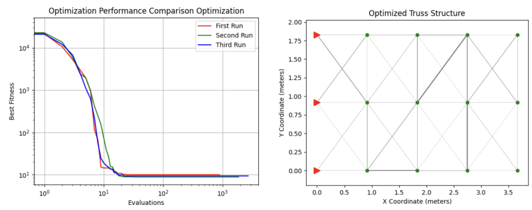

Figure 4. (a) Objective Function with Respect to the number of evaluation (b) Truss Bars Area

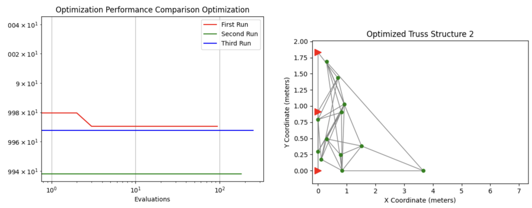

Figure 5. (a) Objective Function with Respect to the number of evaluation (b) Truss Shape

3.1 Optimization with 36 bars

In the 2024 benchmark, an additional challenge was introduced to test the robustness of the algorithm. Therefore, a truss structure comprising 15 nodes and 36 bars was analyzed.

The best results for optimizing the area and shape of this structure are respectively: 8.452 and 89.954.

In this context as well, the first two diagrams in Figure 4 depict the optimization of the structure in terms of the area of the bars, while Figure 5 illustrates the optimization concerning the shape of the truss.

From the analysis of the graphs, it is evident that the BOA algorithm performs better in optimizing the area of the bars but is less effective in determining the optimal coordinates.

In conclusion, while the BOA has proven to be an efficient and effective tool for structural optimization in engineering, it is critical for users to understand its limitations as a metaheuristic. Future work could focus on combining BOA with other optimization techniques, adjusting its parameters for better convergence, or applying it to other complex engineering problems to further explore its capabilities and limitations.

References

1. A. Andrade-Campos and J. Dias-de-Oliveira, *Benchmark 2024: Structural optimisation of a ten-bar- truss*, 2024.
2. Arora, Sankalap and Singh, Satvir, *Butterfly optimization algorithm: a novel approach for global optimization*, Soft Computing, 2019.