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# OPTIMIZATION OF LAMINATED COMPOSITES PLATES USING GLOWWORM ALGORITHM

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**Abstract.** *In this paper, the authors propose the use of the Glowworm Swarm Optimization algorithm, GSO, a recently proposed algorithm for the simultaneous computation of multiple optima of multimodal functions, on a real world problem of structural engineering, the composite laminates buckling load maximization. The function to be optimized is multi-modal, and thus the exploration ability of GSO allows the attainment of a better comprehension of function landscape and also allows the designer to select alternative solutions that could be considered better when all the constraints present in the real world application, not easily represented in the theorical optimization problem, are taken into account.*

## 1 INTRODUCTION

Composite material are nowadays widely used in several areas of engineering. One of the key factors of composites success is the flexibility in material design [1], flexibility of great help in achieving the best structural performance.

The design problem could be expressed as an optimization problem where one or more characteristics of the materials are used as design variables. Usually the resulting problems are higly multimodal and the proposed algorithms tries to find either the global optimum or all global optimum [2].

However, due to the difficulty to fully represent in the theorical optimization problem all the constraints present in the real world application, the knowledges of global and local optimum could be of great help to the designer. The attainment of a better comprehension of function landscape and the possibility to consider alternative solutions, sub-optimal for the theorical optimization problem, but possibly optimal taking into account all the constraints, are the principal advantages of this approach.

In the present work the composite laminates buckling load maximization is examined by mean of glowworm algorithm [3], a recently proposed algorithm for the simultaneous computation of multiple optima of multimodal functions.

The paper is organized as follows: after presenting the basic of the glowworm, the optimization problem is stated. Then, the results for standard benchmark problems are discussed and compared to results available in literature.

## 2 GLOWWORM SWARM OPTIMIZATION (GSO) ALGORITHM

GSO belongs to the general class of swarm intelligence algorithms. After an initial random distribution of possible solutions in the search space every solution tries to find a better state, i.e. a better solution, using informations carried by other solutions. The algorithm follows the natural metaphore of glowworms and therefore every solution is called glowworm. The generic glowworm *i* is characterized by the position in the search space **x**, the light intensity (*luciferine*) $l_i$ and by a neighborhood range $r_i$.

The GSO pseudo-code is reported in 1 from [3].

GLOWWORM SWARM OPTIMIZATION (GSO) ALGORITHM

Set number of dimensions $= m$
Set number of glowworms $= n$
Let $s$ be the step size
Let $x_i(t)$ be the location of glowworm $i$ at time $t$
*deploy_agents_randomly*;
for $i = 1$ to $n$ do $\ell_i(0) = \ell_0$
$r_d^i(0) = r_0$
set maximum iteration number $=$ *iter_max*;
set $t = 1$;
while ($t \leq$ *iter_max*) do:
{
for each glowworm $i$ do: % Luciferin-update phase
$\ell_i(t) = (1-\rho)\ell_i(t-1) + \gamma J(x_i(t))$; (1)

for each glowworm $i$ do: % Movement-phase
{
$N_i(t) = \{j : d_{ij}(t) < r_d^i(t); \ell_i(t) < \ell_j(t)\}$;
for each glowworm $j \in N_i(t)$ do:
$p_{ij}(t) = \frac{\ell_j(t)-\ell_i(t)}{\sum_{k\in N_i(t)} \ell_k(t)-\ell_i(t)}$; (2)
$j = select\_glowworm(\vec{p})$;
$x_i(t+1) = x_i(t) + s\left(\frac{x_j(t)-x_i(t)}{\|x_j(t)-x_i(t)\|}\right)$ (3)
$r_d^i(t+1) = \min\{r_s, \max\{0, r_d^i(t) + \beta(n_t - |N_i(t)|)\}\}$; (4)
}
$t \leftarrow t+1$;
}

Figure 1: GSO algorithm.

After an initial deployment of random solutions in the search space, each solution characterized by a fixed initial value of luciferine $l_0$ and by a fixed initial value of range $r_0$, an iteration procedure begins till a final condition is met.

Each iteration is characterized by three phases.

*PHASE 1: Luciferine-update:* each glowworm changes his luciferine value, see (1) in figure 1. The luciferine decays by a factor $/ro$ and is increased proportionally to the value of the objective function $J(\mathbf{x})$. In this way better solutions will increase the luciferine value.

*PHASE 2: Movement:* each glowworm tries to find a better state. In this phase each glowworm changes his position accordingly to the informations gathered by other glowworms in his neighborhood range . The neighbors $N_i$ of glowworm $i$ are defined by all the glowworms that have an higher luciferine value of glowworm $i$ and a distance less of neighborhood range $r_i$.

Each glowworm decides, using a classical roulette wheel selection (see (2) in figure 1), to move towards a neighbor (see (3) in figure 1).

*PHASE 3: Neighborhood range-update:* Each neighborhood range $r_i$ is updated increasing it if the number of neighboors is less than a fixed value $n_t$, and lowering it if the number is higher, see (4) in figure 1

Further details could be found in [3].

## 3 COMPOSITE LAMINATES DESIGN OPTIMIZATION

Considering a rectangular composite plate simply supported and subjected only to normal compressive loads the plate buckles into $m$ and $n$ half waves in the x and y direction, respectively, when the loads reach the values $\lambda_b N_x$ and $\lambda_b N_y$.

In the general case of laminate with multiple anisotropic layers and without any stacking sequence symmetry the problem doesn't admit a simple solution. If we assume particular constraints on the stacking sequences, i.e. plates for which the bending twisting coefficients are zero are so small in respect to the other coefficients to be assumed zero, using the classical laminate theories [4] the buckling load factor $\lambda_b$ could be found as:

$$\lambda_b(m,n) = \frac{\pi^2}{a^2}\frac{m^4 D_{11} + 2(D_{12}+2D_{66})r^2m^2n^2 + r^4n^4D_{22}}{m^2N_x + r^2n^2N_y} \tag{1}$$

where $a$ and $b$ are the lamina dimensions; $r = \frac{a}{b}$ the aspect ratio; $N_x$ and $N_y$ the applied loads; $D_{ij}$ the bending stiffness of the composite plate depending from the assumed stacking sequence of the laminate.

The smallest value of $\lambda_b$ over all possibles values of $m$ and $n$ represents the lowest value of loads for which the buckling conditions are reached and hence the critical buckling load factor $\lambda_{cb}$. According to [5] limiting the values of $m$ and $n$ to 1,2 gives a good estimation of critical buckling load, so for an assigned plate geometry the optimization problem could be stated as:

$$\max_{D_{ij}}\left(\min_{m,n}\lambda_b(m,n);\quad m,n \in 1,2\right) \tag{2}$$

The terms $D_{ij}$ could be expressed knowing the fiber orientations $\theta_k$ and the elastic properties of the material along the principal directions $E_{11}^k$, $E_{22}^k$, $G_{12}^k$, $\nu_{12}^k$ of each lamina, [4]. For an assumed plate geometry the design variables are hence the elastic properties and the fiber orientations of each lamina.

In this paper a laminate made by graphite epoxy lamina of constant thickness t was considered, the elastic properties and thickness of the material are the following:

$E_{11}$ = 127.6 GPa; $E_{22}$ = 13.0 GPa; $G_{12}$ = 6.4 GPa; $\nu_{12}$ = 0.3.

The ply thickness is $t$ = 0.127 mm.

The laminate has length $a = 0.508$ m, width $b = 0.254$ m, and is made by 64 plies. total thickness $t = 8.128$ mm , [5]. The only design variables are hence the angles $\theta_k$ of each lamina. We applied GSO to a different set of allowed fiber orientations and of different constraints on the laminate stacking sequence able to reduce the number of independent variables. Table 1 shows the different set of possible fiber orientations, the constraint adopted on the stacking sequence and the number of independent variables for each case analyzed in the present paper.

The *continuous relaxation approach* is adopted in the optimization algorithm, i.e. the discrete variables are replaced by continuous ones and in the evaluation of the objective function are transformed in the allowed discrete values. This choice is suitable due to the natural order in the design variables space.

| Fiber directions | Constraints | No. design variables |
|---|---|---|
| $P_1 = [0, 45, 90]$ | symmetric, balanced | 16 |
| $P_2 = [0, 30, 60, 90]$ | symmetric | 32 |
| $P_3 = [0, 15, 30, 45, 60, 75, 90]$ | symmetric | 32 |

Table 1: Design problems analyzed.

| Problem | No. of sub-optima |
|---|---|
| $P_1$ | 9 |
| $P_2$ | 32 |
| $P_3$ | 32 |

Table 2: Number of distinct global optima.

Using the values of optimal solutions reported in [2] in Table 2 are reported the number of distinct sub-optima found using GSO. A solution $\mathbf{x}$ is considered sub-optimal if $(J(\mathbf{x}^*) - \mathbf{J}(\mathbf{x}))/\mathbf{J}(\mathbf{x}^*) < \epsilon$ where $\mathbf{x}^*$ is the assumed global optima. In table 2 $\epsilon = 0.01$.

## 4 CONCLUSIONS

In this paper a recent algorithm proposed in literature, GSO, for the simultaneous computation of multiple optimal solution has been applied to a difficult multi-modal problem of composite laminates buckling load maximization. As it can be noted the algorithm is capable to attain good performance and the application to structural optimization problems seems promising. Further studies are necessary to better understand the capacity of the algorithm to solve different structural optimization problems and the influence of different parameters on the algorithm's performances.

## REFERENCES

[1] Barbero, E. J., *Introduction to Composite Materials Design*. Taylor & Francis, 1998.

[2] Candela, R., Cottone, G., Fileccia Scimemi, G., Riva Sanseverino, E.. *Composite laminates buckling optimization through Levy based Ant Colony Optimization*. Proceedings of the 23th (IEA-AIE 2010).

[3] K. Krishnanand and D. Ghose, *Glowworm swarm optimization for simultaneous capture of multiple local optima of multimodal functions* Swarm Intelligence, vol. 3, no. 2, pp. 87-124, June 2009.

[4] Reddy J.N.: Mechanics of Laminated Composite Plates and Shells - 2nd e. CRC press (2004)

[5] Soremekun G., Gurdal Z., Haftka R.T., Watson L.T.: Composite laminate design optimization by genetic algorithm with generalized elitist selection Computers and Structures **79** (2001) 131-143