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Optimization of Truss Structures using Cuckoo Search Algorithm

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Abstract: In recent years optimization techniques are being used in a wide spectrum of industries, including aerospace, automotive, chemical, electrical, mechanical, civil and manufacturing industries. With rapidly advancing computer technology, computers are being more powerful and correspondingly the size and the complexity of the problems being solved using optimization techniques are also increasing. In civil engineering field, optimization of truss structures using metaheuristic approaches is gaining much importance and found to be more successful in the field of structural optimization, due to its viability and reliability of promising solutions that are being generated at each time step. Several researchers have contributed in the field of structural optimization with an aim to find optimal design of structures. In the present work, an attempt has been made to develop an enhanced version of cuckoo search algorithm that mimics the principle of brood parasitic behaviour. The viabilities of the proposed algorithm are tested through a series of truss problems to find the minimum weight design. The solutions obtained using the proposed algorithm is found to be better in terms of minimum weight compared to those of other algorithm like Ant Colony Optimization algorithm, Genetic Algorithm etc.,

Keywords*: Truss Structures, Optimization, Algorithms, Cuckoo Search*

I. Introduction:

Structural design is a branch of Engineering that deals with systems comprised from a set of structural members. These members may be characterized as either truss or frame elements, connected by pinned or fixed joints. In design construction and maintenance of any engineering system, engineers have to take many technological and managerial decisions at several stages. Structural optimization is the process of finding the conditions that give the maximum or minimum value of a function. Optimization can be taken to mean minimization since the maximum of a function can be found by seeking the minimum of the negative of the same function. An optimization algorithm is a Procedure which is executed iteratively by comparing various solutions till the optimum or a satisfactory solution is found. In many industrial design activities, optimization is achieved indirectly by comparing a few chosen design solutions and accepting the best solution.

Optimization algorithms begin with one or more design solutions supplied by the user and then iteratively check new design solutions in order to achieve the true optimum solution. The term "**space structure**" refers to a structural system that involves three dimensions. In practice, the term "**space structure**" is simply used to refer to a number of families of structures that include grids, barrel vaults, domes, towers, cable nets, membrane systems and foldable assemblies. Space structures cover an enormous range of shapes and are constructed using different materials such as steel, aluminum, timber, concrete, fiber reinforced composites, glass, or a combination of these.

The advantages of space structures are listed below:

(i) They are three dimensional structures which can withstand loads from any direction.
(ii) They are hyper static, and buckling of some compression members does not cause the whole system to collapse as has been demonstrated by mathematical models and experiments.
(iii) Their rigidity minimizes deflections.
(iv) Their composition allows factory pre-fabrication in modular elements, which are easily transported. Fabrication precision ensures ease of assembly and erection.
(v) They allow a wide choice of support positions owing to modular construction.
(vi) For double layer space structures, the space between the two layers may be used to install electricity, electrical and thermal piping, etc.
(vii) Installation is carried out by bolting and can be done regardless of the atmospheric conditions.
(viii) They provide aesthetic qualities.

Nowadays Structural optimization plays an important role in an engineering field. It helps to an engineer by means of making the structure economical, light weight, etc., It is also applied in the field of aircraft and aerospace structures for minimum weight, electrical network, inventory control etc.,

In this paper, a meta heuristic method known as cuckoo search algorithm is utilized to determine optimum design of truss structures for both discrete and continuous variables. This algorithm was recently developed by Yang and Deb and is based on the obligate brood parasitic behaviour of some cuckoo species together with the Levy' flight behaviour of some birds and fruit flies. The CS is a population based optimization algorithm and similar to many others meta heuristic algorithms starts with a random initial population which is taken as host nests or eggs. The CS algorithm essentially works with three components selection of the best by keeping the best nest of solutions; replacement of the host eggs with respect to the quality of the new solutions or cuckoo eggs produced based on randomization via Levy flights globally and discovery of some cuckoo eggs by the host birds and replacing according to the quality of the local random walks.

II. Structural optimization:

Methods:

Optimization of structures can be broken down to three categories: topology, size, and shape. All three categories generally have the objective of mass minimization with optional stress or displacement constraints.

Topology optimization-- variance of element-node connectivity to find an optimal layout design. Difficulties may arise when a change truss topology causes the structure to become a mechanism.

Size optimization-- variance of element cross sectional properties, which may be continuous or discrete variables.

Shape optimization-- movement of nodes to change the shape of the structure without changing the topology. The element-node connectivity remains intact.

III. Cuckoo search

In order to explain the cuckoo search algorithm first we will explain about some cuckoo's breeding behavior and further we will discuss about the proposed algorithm.

Cuckoo breeding behaviour:

The Common Cuckoo is a brood parasite; it lays its eggs in the nests of other birds. At the appropriate moment, the hen cuckoo flies down to the host's nest, pushes one egg out of the nest, lays an egg and flies off. The whole process takes about 10 seconds. A female may visit up to 50 nests during a breeding season. Common Cuckoos first breed at two years old.

The cuckoos are an extremely diverse group of birds with regards to breeding systems. The majority of species are monogamous, but there are exceptions. The anis and the Guira Cuckoo lay their eggs in communal nests, although this behaviour is not completely cooperative; a female may remove others' eggs when laying hers. Polyandry has been confirmed in the African Black Coucal and is suspected to occur in the other coucals, perhaps explaining the reversed sexual dimorphism in the group. The majority of cuckoo species, including malkohas, couas, coucals, and roadrunners and most other American cuckoos, build their own nests, although a large minority engage in brood parasitism. Most of these species nest in trees or bushes, but the coucals lay their eggs in nests on the ground or in low shrubs. Though on some occasions non-parasitic cuckoos parasitize other species, the parent still helps feed the chick. Non-parasitic cuckoos, like most other non-passerines, lay white eggs, but many of the parasitic species lay coloured eggs to match those of their passerine hosts.

*Tapera*have evolved in such a way that female parasitic cuckoos are often very specialized in the mimicry in colour and pattern of the eggs of a few chosen host species. This reduces the probability of their eggs being abandoned and thus increases their reproductivity. Furthermore, the timing of egg-laying of some species is also amazing. Parasitic cuckoos often choose a nest where the host bird just laid its own eggs.

The young of all species are altricial. Non-parasitic cuckoos leave the nest before they can fly, and some New World species have the shortest incubation periods among birds.

A. Cuckoo search algorithm:

For simplicity in describing our new Cuckoo Search [10], we now use the following three idealized rules:

- Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest;
- The best nests with high quality of eggs (solutions) will carry over to the next generations;
- The number of available host nests is fixed, and a host can discover an alien egg with a probability pa ε [0, 1].

In this case, the host bird can either throw the egg away or abandon the nest so as to build a completely new nest in a new location.

For simplicity, this last assumption can be approximated by a fraction pa of the n nests being replaced by new nests (with new random solutions at new locations). For a maximization problem, the quality or fitness of a solution can simply be proportional to the objective function. Other forms of fitness can be defined in a similar way to the fitness function in genetic algorithms.

Objective function f(x), $x = (x_1 \ldots\ldots\ldots\ldots\ldots\ldots x_d)^T$;
Initial a population of n host nests x_i (i = 1, 2, ………, n);
While (t < MaxGeneration) or (stop criterion);
    Get a cuckoo (say i) randomly by Levy flights;
    Evaluate its quality / fitness Fi;
    Choose a nest among n (say j) randomly;
    if (Fi > Fj),
        Replace j by the new solution;
    End
    Abandon a fraction (pa) of worse nests
        [and build new ones at new location via Levy flights];

Keep the best solution (or nests with quality solutions);

Rank the solutions and find the current best;

end while

Postprocess results and visualization;

It is relatively easy to implement the algorithm, the following flow chart diagram will help us to analyze the problem.

In the first step, according to the pseudo code one of the randomly selected nests is replaced bya new solution produced by random walk with Levy' flight around the so far best nest considering the quality. But in the new version, all the nests except the best one is replaced in one step, by a new solutions. When generating new solutions $x_i^{(t+1)}$ for the i^{th} cuckoo, a Levy' flight is performed using the following equation

$$X_i^{(t+1)}=x_i^{(t)}+a.S \qquad (1)$$

In the second step, the *pa* fraction of the worst nests are discovered and replaced by new ones. However, in the new version the parameter *pa* is considered as the probability of a solution component to be discovered.

IV.25 bar space truss:

In this paper, the 25 bar space truss was discussed with displacement constraint. The 25 bar space truss which was originally introduced by Venkaya et al. the above 25 bar space truss has been taken as a vehicle by many researchers to prove the effectiveness of their proposed model. In this study, the same 25 bar truss has been taken as a vehicle by adopting the same loading condition and boundary condition that were taken by [7], [2], [8], [3].

The optimal design of space truss can be considered as weight minimization problem. The objective function f(x) can be defined as a vector for selecting the cross sectional areas of members, which minimize the weight of the truss structure.

$$F(x)=\sum_{i=1}^{n}\rho A_i l_i \qquad (2)$$

where,

'A_i' - cross-sectional area of the structural member,

'Li'- length of the member

'ρ'- unit weight of the member

Constraints

- $U_{actual}<U_{allowable}$
- $P_{actual}<P_{allowable}$

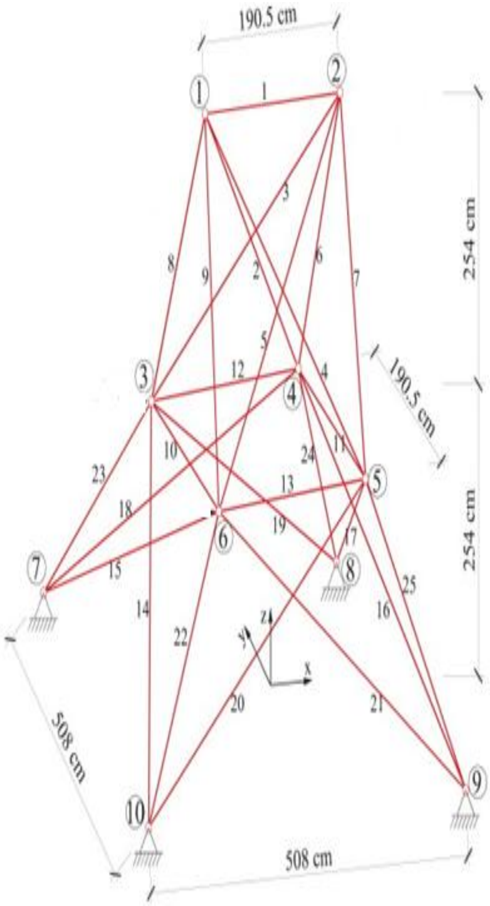

Fig 1. 25 bar space truss

A. Stiffness matrix:

$$\bar{K}=\frac{E.A_x}{L}\begin{bmatrix} C_X^2 & C_YC_X & C_ZC_X & -C_X^2 & -C_YC_X & -C_ZC_X \\ C_XC_Y & C_Y^2 & C_ZC_Y & -C_XC_Y & -C_Y^2 & -C_ZC_Y \\ C_XC_Z & C_YC_Z & C_Z^2 & -C_XC_Z & -C_YC_Z & -C_Z^2 \\ -C_X^2 & -C_YC_X & -C_ZC_X & C_X^2 & C_YC_X & C_ZC_X \\ -C_XC_Y & -C_Y^2 & -C_ZC_Y & C_XC_Y & C_Y^2 & C_ZC_Y \\ -C_XC_Z & -C_YC_Z & -C_Z^2 & C_XC_Z & C_YC_Z & C_Z^2 \end{bmatrix}$$

$$C_X=\frac{x_j-x_i}{L}$$

$$C_Y=\frac{y_j-y_i}{L}$$

$$C_Z=\frac{z_j-z_i}{L}$$

$$L=\sqrt{(x_j-x_i)^2+(y_j-y_i)^2+(z_j-z_i)^2}$$

After developing the stiffness matrices for each member of the entire structure in terms of global coordinates, these matrices can be assembled to form the global stiffness matrix for the entire structure. Total stiffness at a coordinate is the sum of the stiffness contributed to that coordinate by each element attached to that coordinate. Table 1 listed the optimium design for the 25 bar space truss.

Table 1: Optimum design for the 25 bar space truss

Element group	Cross sectional areas (mm^2)		
	Saka	Bland	CS
B1	6.45	6.4516	1910.6
B2	1327.74	64.516	1812.2
B3	1927.74	2193.544	259.6
B4	6.45	6.4516	1827.3
B5	6.45	1612.9	1267.1
B6	449.03	516.128	200.9
B7	1077.42	64.516	561.7
B8	1672.25	2516.124	1096.7
Total weight(Kg)	247.31	209.3	197.03

V. Conclusion:

From the comparison study of the performance of Cuckoo Search with Genetic Algorithm and Particle Swarm Optimization, we know that our new Cuckoo Search is very efficient and proves to be superior for almost all the test problems. This is partly due to the fact that there are fewer parameters to be fine-tuned in Cuckoo Search than in Particle Swarm Optimization and genetic algorithms. The selection of the best by keeping the best nests or solutions is equivalent to some form of elitism commonly used in Genetic Algorithms, which ensures the best solution is passed onto the next iteration and there is no risk that the best solutions are cast out of the population. In future, this CS algorithm is expanded to shaping optimization of truss structures.

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