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Applications of Harmony Search Algorithm in Structural Engineering

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Abstract

Harmony search Algorithm (HSA) is mostly preferred for solving optimization problems and gives optimum solution of the problems. . It is based on improvisation of harmony in music process where musicians improvise their instruments' pitch by searching for a aesthetically pleasant harmony. As the musicians in improvisation process try to find the best harmony in terms of aesthetics, the decision variables in optimization process try to be the best solution in terms of objective function. In the present work, the harmony search method is studied with an attempt to use it to solve various structural optimization problems. Harmony search can be more effective than some of the optimization available right now like genetic algorithms, particle swarm algorithm, ant colony algorithm, gravity search algorithm etc. The programming language used in this work is Visual Basic-macro excel. The programs for harmony search algorithm is developed in macro and their reliability is checked by verifying it with various mathematical optimization problems.

1 Introduction

Optimization is a method which gives best solution for a given problem satisfying all its requirements. Every optimization problem has three components. First one is the objective function. Second the side constraints followed by behavioral or functional constraints. The objective function is the criteria for comparing various alternative solution available for a given optimization problem. Objective function is a mathematical expression formed by variables. Variables are the entities for a given optimization problem. The variables are bounded within the lower and upper range up to which they can vary. These are called side constraints of the given problem. Other than side constraints the variables must also satisfy certain functional requirements. These requirements are called functional constraints. Let's take example of optimization of a rectangular beam. The objective is to minimize cross section of the beam. Hence, objective function can be formed as b*d. Where "b" and "d" are the breadth and depth of the beam. Thus "b" and "d" are called variables of the problem. Suppose breadth

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should be between 200mm to 350 mm only. And depth should not be more than 3 times breadth. These are called side constraints. The deflection of the beam should not be more then span/250. This is called functional constraint in context of given problem.

There are various methods available for optimization. Conventional methods require more computational time and also it is very tedious job. So various heuristic methods are developed which are based on natural principles. These methods are widely adopted since; they are reliable in context of conventional methods.

Different Metaheuristics methods available are:

- Simulated Annealing
- Genetic Algorithms
- Ant Colony Optimization
- The Harmony Search Method,
- Gravitational Search
- Particle Swarm Optimization
- Bee Colony Optimization
- Bacterial Forging Optimization

Metaheuristics method utilizes nature's concept into optimization problems. Still studies are going on to develop new optimization techniques based on natural phenomenon.

Zong Woo Geem and Joong Hoon Kim in 2001 [1], developed a new heuristic algorithm inspired by improvisation of music players, named Harmony Search (HS). Harmony Search algorithm can solve a different continuous- variable problem as well as complex problems, and gives better result than other existing heuristic methods in specified optimization problems.

S. Gholizadeh, A. Barzegar [2], proposed a modified harmony search (MHS) algorithm for size and shape optimization of structures. This MHS algorithm uses elitism. In fact, the MHS is a multi-layered upgradation of the HS and in each level a new harmony memory is created with the help of the information of the previous levels. The numerical results show that use of MHS not only better solutions can be found but also a noticeable reduction in computational time may be achieved.

Sachin A. Patil, D. A. Patel [3], gave an improved harmony search algorithm (IHSA). In IHSA few disadvantages of HSA are removed and so that performance of HSA is improved. In IHSA Harmony search parameters par and bw are improved at every iteration. The IHSA showed faster convergent then HSA.

Moacir Kripka, Deise Boito [4], carried out research on Optimization of Reinforced Concrete Frames by Harmony Search Method. This work dealt with the problem of optimization of reinforced concrete building frames, following the requirements of the Brazilian standard NBR 6118 (ABNT 2007), and using the Harmony Search optimization method. To the examples analyzed, the optimization method was quite efficient in minimizing structural cost. The software has been an important tool for pre-sizing of reinforced concrete elements.

Mohamed F. El-Santawy and A. N. Ahmed [5], introduced a new a new Multi-Objective Evolutionary technique. The new method uses Harmony Search optimization to Chaos search. The well-known Fitness Sharing method is adopted to employ the size of the external archive used by the technique during search. The proposed method is applied to Structural optimization which is one of the most challenging areas in Multi Objective Optimization.

2 Harmony Search Method

The harmony search algorithm is a newly developed optimization algorithm developed by Geem, Kim and Loganathan in 2001. It is based on an analogy to musical improvisation of jazz, where musicians try to find, through repeated iterations, the aesthetically pleasant harmony given (optimum solution to a problem). Iterations are called improvisations or practice. Variables analogs to musical instruments. Values for variables are the notes of instruments. Every solution is called harmony. Through repetitive random search technique, a new harmony vector is generated which replaces worst harmony in harmony memory. The analogy between harmony search and optimization problem is shown in table 1.

Harmony search	**Optimization problem**
Musical Instruments	Components of the system being optimized
Notes: sets of possible tones to be played by musicians	design variables: set of possible design values for system components
Chord: specific collection of notes	design: specific collection of design variables
Harmony: synthesis of all notes	objective function: synthesis of all design variables
Goal: maximize harmony	goal: extremize objective function
Process: trial and error, improvise new harmonies and try them out	process: improvise on designs by trial and error

Table 1: Analogy between harmony search and optimization problem

In general, mathematical optimization problems, harmony search uses the harmony memory (HM) to store the solutions, and the harmony memory size (HMS) gives the number of solutions stored in the harmony memory. The harmony memory is initialized by assigning random values to every design variable from its possible range of values. With the help of initial HM, the value of the objective function for every harmony is calculated and the harmony with the worst objective function value is determined. In each iteration a new harmony is improvised and its objective function is calculated, if it gives a better objective function value, it replaces the worst harmony in the harmony memory and the harmony memory is updated. The previous procedure is again repeated till a termination criterion is met which is normally maximum number of iterations or until no further improvement of harmony or design performance can be achieved.

The following figure (fig.1) shows the flowchart of harmony search algorithm.

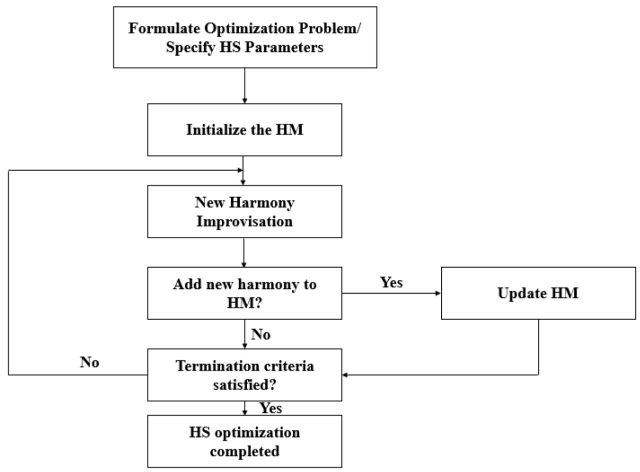

Figure 1: Flow chart of harmony search method

For the purpose of study of harmony search method, a visual basic macro program was developed in excel and a mathematical optimization problem was solved using the developed program. The problem is shown below:

Minimize,

$$f(X) = 5.358547 * (x3)^2 + 0.8356891 * x1 * x5 + 37.293239 * x1 - 40792.141$$

subject to,

$$g1 = 85.334407 + 0.0056858 * x2 * x5 + 0.0006262 * x1 * x4 - 0.0022053 * x3 * x5$$

$$g2 = 80.51249 + 0.0071317 * x2 * x5 + 0.0029955 * x1 * x2 + 0.0021813 * (x3)^2$$

$$g3 = 9.300961 + 0.0047026 * x3 * x5 + 0.0012547 * x1 * x3 + 0.0019085 * x3 * x4$$

where,

$$0 \le g1 \le 92;\ 90 \le g2 \le 110;\ 20 \le g3 \le 25$$

and,

$$78 \le x1 \le 102;\ 33 \le x2 \le 45;\ 27 \le x3, x4, x5 \le 45$$

The results are tabulated below:

Particular	Present work	Literature
x1	78.073	78.000
x2	34.545	33.000
x3	30.114	29.995
x4	44.009	45.000
x5	33.828	36.775
F	-30814.0	-30664.9
g1	91.883	91.999
g2	98.903	98.840
g3	19.571	19.991

Table 2: Comparision between present work and literature

By comparing the results, it is seen that harmony search method is an effective method in finding out optimum solution of a given mathematical problem.

3 Applications in Structural engineering

Various Visual basic macro program was developed for harmony search method with improved par and bw parameters. Exterior penalty function method is used to construct an unconstrained optimization problem. The developed programs are applied to various structural optimization problems. The problems are as follows:

3.1 Two Bar Truss Problem

The objective is to design of the truss for minimum volume. The optimization problem for three variables y (vertical distance between B and C in m), x_1 (area of AC in cm^2) and x_2 (area of BC in m) is constructed as follows:

Minimize, $f = x_1 (16+ y^2)^{1/2} + x_2 (1+ y^2)^{1/2}$

Subject to,

$\sigma_{AC} <= 100$ MPa

$\sigma_{BC} <= 100$ MPa

Where,

$\sigma_{AC} = 20 (16+ y^2)^{1/2} \div x_1 y$

and $\sigma_{BC} = 80 (1+ y^2)^{1/2} \div x_2 y$

$x_1, x_2 \geq 0$ and $1\text{m} \leq y \leq 3\text{m}$

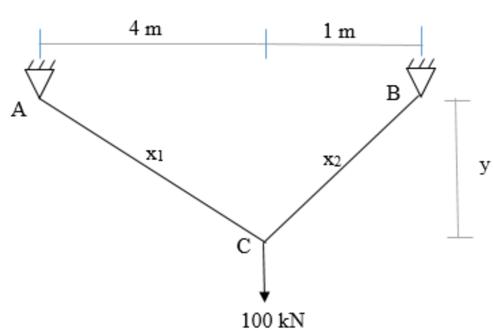

Figure 2: Two bar truss problem

The best solution is obtained as $\{x_1, x_2, y\} = \{0.4474, 0.8935, 1.9977\}$ with a minimum volume of 0.03996 m^3. Mohamed F. El-Santawy and A. N. Ahmed [5], developed a chaotic harmony search technique and used it to find the optimum solution for same problem. The range for optimum volume in their technique is between 0.0375 to 0.0537 m^3. By comparison it is seen that the proposed program gives optimum value within the range suggested by El- Santawy and A. N. Ahmed.

3.2 Pressure Vessel Design

A cylindrical vessel is to be optimized for minimization of cost. The objective is to minimize the total cost, which includes the cost of material, forming and welding.

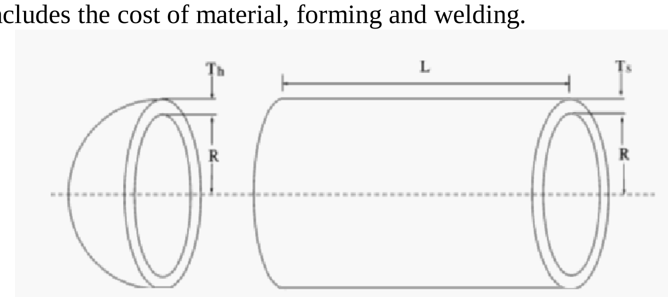

Figure 3: Pressure Vessel design

The design variables are : Ts (thickness of the shell, x1), Th (thickness of the head, x2), R (inner radius, x3) and L(length of cylindrical section of the vessel, not including the head, x4). Ts and Th are integer multiples of 0.0625 inch, which are the available thickness of rolled steel plates, and R and L are continuous. The problem can be formulated as follows,

Minimize,

f = 0.6224 * x1 * x3 * x4 + 1.7781 * x2 * ((x3)^2) + 3.1661 * ((x1)^2) * x4 + 19.84 * ((x1)^2) * x3

subject to,

g1 = -x1 + 0.0193 * x3

g2 = -x2 + 0.00954 * x3

g3 = (-(22 / 7) * ((x3)^2) * x4) - ((4 / 3) * (22 / 7) * ((x3)^3)) + (1296000)

g4 = (x4 - 240)

g5 = (-x1 + 1.1)

all $g_j \leq 0$, j= 1, 2, 3, 4, 5

and,

$1.10 \leq x1 \leq 6.1875$

$0.6 \leq x2 \leq 6.1875$

$40 \leq x3 \leq 80$

$20 \leq x4, x5 \leq 60$

After running the macro, the optimum solution obtained is tabulated in table 3.

Particular	Present study	Wu and chow(2001)
x1	1.125	1.125
x2	0.625	0.625
x3	58.219	58.1978
x4	44.037	44.293
F	7200.202	7207.775
g1	-0.001	-0.00178
g2	-0.07	-0.06979
g3	-0.249	-0.191
g4	-195.963	-195.707

Table 3: Comparision between present work and literature

Wu and chow developed a program to find the optimum solution of given problem using the GA algorithm. The comparison between their results and present study is shown in table 3.

From the table of comparison, it is seen that the proposed macro program gives a better solution than proposed by Wu and Chow.

3.3 Optimum design of R.C. concrete beam

The problem consists of finding optimum rectangular section of a given simply supported beam. The program takes data from the user like, grade of concrete, grade of steel, permissible bounds for breadth and depth of beam.

The side constraints are given by the user and other constraints are that, the deflection should be within permissible limits and max amount of reinforcement should not exceed 4 %. This program follows the procedure suggested by IS: 456,2000 for finding out the reinforcement required both in tension as well as compression.

The objective function is

Minimize f = b * d

Where, b= breadth of the beam

d= depth of the beam

subject to,

$b_l < b < b_u$

$d_l < d < d_u$

Asc and Ast < 4 % of b*d

Def < span / 250

	A	B	C	D	E	F	G
1	Design a R. C. Beam with following data.						
2							
3	span	10	m				
4	LL	5	KN/m				
5	concrete	M	20				
6	steel	Fe	415				
7	bounds						
8	b	200	400				
9	d	300	500				
10							
11	Optimum design						
12	b	d	f	Asc	Ast	def	Beam
13	205	350	71750	95.64632	696.6504	39.750906	D.R.C
14							

Figure 3: Design of R.C. Beam (excel sheet)

After running the macro program, the user will be able to see min cross section, amount of compression and tension steel required and type of the beam i.e. singly reinforced or doubly reinforced beam.

4 Conclusion

Harmony search algorithm is relatively new meta-heuristic algorithm which is very important in optimization problems. It has been applied to divergent problems in recent years and results are very encouraging when compared to other meta-heuristic algorithms. HSA is very flexible to implement simple to apply.

Compared to gradient based optimization algorithms the harmony search method requires lesser mathematical requirements and does not require initial value setting of decision variables. HSA uses random searches so derivative information is also not needed.

This paper describes the application of harmony search algorithm in structural engineering by dealing with the programs related to two bar truss problem, pressure vessel design and design of R.C. Beam etc. In this paper the algorithm used is a modified one by improving HS parameters at each iteration. The results show that the improved algorithm shows better solution requiring fewer iteration cycles.

There still needs improvement in the existing program, as there are chances of getting local optimum rather than global optimum. There is possibility of hybridizing the harmony search algorithm with other existing meta heuristics like, GA, PSO, SA etc. The research needs to be done in this field.

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