ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 1, January 2013

An Overview: Improved Harmony Search Algorithm and Its Applications in Mechanical Engineering

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Abstract*— Harmony search algorithm is developed in the year of 2001 and after that it is modified and hybridized by other researcher. The aim of this paper is to inform the readers about Harmony search algorithm (HSA) and improved harmony search algorithm (IHSA) and applications of IHSA in engineering. The paper is divided in four sections, in first section optimization and types of optimization problem is discussed. In second section literature review of HSA, IHSA and other research related to HSA is briefly discussed. Third section talks about the applications of IHSA are discussed. Lastly the current state of the study is discussed.

Key Words: **Optimization Technique, Harmony Search Algorithm, Improved Harmony Search Algorithm, Engineering Applications.**

I. INTRODUCTION

Optimization can be defined as the process of finding best solution or result under given circumstances. Generally optimization is used for maximizing or minimizing the value of a function, it may be local optimum or global optimum. In optimization there are different types of problems are being utilized like, Liner optimization, Non liner optimization, Dynamic optimization etc. and all have different techniques for solving. In this paper evolutionary algorithm Harmony search is discussed.

Z. W. Geem et al. in 2001 [1] developed a New Harmony search (HS) meta-heuristic algorithm that was conceptualized using musical process of searching for a perfect state of harmony. This harmony in music is analogous to find the optimality in an optimization process. In music improvisation process musician plays different notes of different musical instrument and find the best combination of frequency for best tune. Similarly in HS method also best combination of available solutions is selected and objective function is optimized. The HS method had been successfully applied to diverse range of problems – structural analysis, mechanical component design, water distribution network, medical imaging, games and many others. HS algorithm has many advantages over other meta-heuristic algorithms [2][5]: (a) HS algorithm imposes fewer mathematical requirements and does not require initial value settings of the decision variables. (b) As the HS algorithm uses stochastic random searches, derivative information is also unnecessary. (c) The HS algorithm generates a new vector, after considering all of the existing vectors, whereas the genetic algorithm (GA) only considers the two parent vectors. These features increase the flexibility of the HS algorithm and produce better solutions. On the basis of HSA M. Mahdavi et al. 2007 [5] developed a new algorithm called Improved Harmony Search Algorithm (IHSA). In this algorithm few drawback of HS method have been removed by modifying the algorithm. According to the algorithm there is a modification has been done in two parameters Pitch Adjusting Rate (PAR) and Bandwidth (BW).

II. LITERATURE REVIEW

Since the 1970s, many meta-heuristic algorithms that combine rules and randomness imitating natural phenomena have been developed to overcome the computational drawbacks of existing numerical algorithms (i.e., complex derivatives, sensitivity to initial values, and the large amount of enumeration memory) when solving difficult and complex engineering optimization problems. These algorithms include simulated annealing, tabu search, particle swarm algorithm, bee colony search, ant colony search algorithm, firefly algorithm, genetic algorithm and other evolutionary computation methods. From above mentioned problem solving techniques genetic algorithm is widely used technique for optimization problems and it gives global solution of the problem.

Z. W. Geem et al. in 2001 [1] developed a New Harmony search (HS) meta-heuristic algorithm having the purpose to produce better solution than other existing algorithm in less number of iterations, which is explained in section 2.1.

In current international literature one can find variety of applications of HSA and number of publications on HSA can be found. After extensive search we found interesting results which are shown in figure 1. After 2004 publications on HSA has been increased and day by day the interest of researchers is increasing.

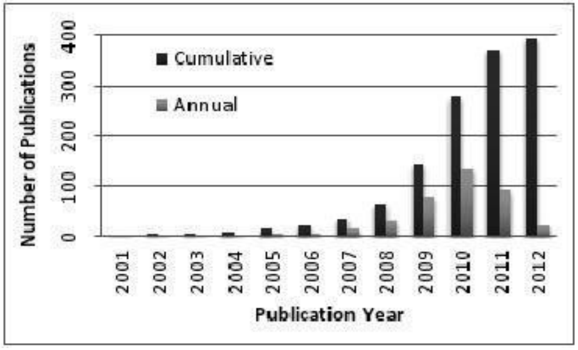


Fig1-Growth of HAS publication (year wise)

A. *Harmony Search Algorithm (HSA)*

Harmony Search was inspired by the improvisation of Jazz musicians. Specifically, the process by which the musicians (who have never played together before) rapidly refine their individual improvisation through variation resulting in an aesthetic harmony.

Steps of harmony search algorithm are shown as flowchart in Figure 2. They are as follows [5]:

Step 1. Initialize the problem and algorithm parameters.
Step 2. Initialize the Harmony Memory (HM).
Step 3. Improvise a New Harmony memory.
Step 4. Update the Harmony memory.
Step 5. Check the stopping criterion.

a. Initialize the problem and algorithm parameters

In Step 1, the optimization problem is specified as follows:

Minimize$f(x)$,

Subject to $x_i \in X_i \, , i = 1,2,3, \dots \dots n$

where $f(x)$ is an objective function; x is the set of each decision variable x_i ; n is the number of decision variables, X_i is the set of the possible range of values for each decision variable, that is $x_i^L \le X_i \le x_i^U$ and x_i^L and x_i^U are the lower and upper bounds for each decision variable.

The HS algorithm parameters are also specified in this step. These parameters are

1. Harmony Memory Size (HMS), or the number of solution vectors in the harmony memory;
2. Harmony Memory Considering Rate (HMCR), HMCR $\in [0,1]$;
3. Pitch Adjusting Rate (PAR) $\in [0,1]$;
4. Number of improvisations (NI), or stopping criterion;

The harmony memory (HM) is a memory location where all the solution vectors are stored.

a. Initialize the harmony memory

In this Step, the HM matrix is filled with as many randomly generated solution vectors as the HMS.

$$\text{HM} = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_n^1 \\ x_1^2 & x_2^2 & \cdots & x_n^2 \\ \vdots & \vdots & \ddots & \vdots \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_n^{HMS} \end{bmatrix}$$

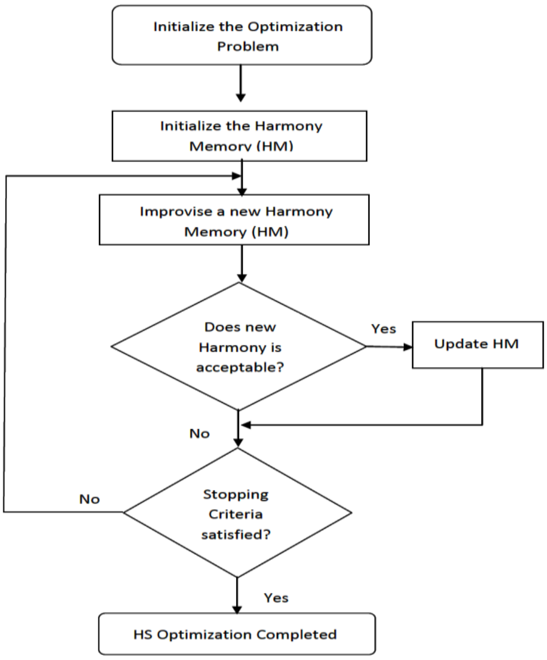


Fig 2-Flowchart of HSA

b. Improvise a new harmony

A New Harmony vector is generated based on three rules: (1) memory consideration, (2) pitch adjustment and (3) random selection. Generating a new harmony is called 'improvisation' [2]. In the memory consideration, the value of the first decision variable x'_1 for the new vector is chosen from any of the values in the specified HM range$(x_1^1 - x_1^{HMS})$. HM is similar to the step where the musician uses his/her memory to generate a tune. Values of the other decision variables are chosen in the same manner. The HMCR $\in [0,1]$, is the rate of choosing one value from the historical values stored in the HM, while (1−HMCR) is the rate of randomly selecting one value from the possible range of values.

$$x'_i \leftarrow \begin{cases} x'_i \in \{x_i^1, x_i^2 \dots . x_i^{HMS} & with\ probability\ HMCR \\ x'_i \in X_i & With\ probability\ (1-HMCR) \end{cases}$$

For example, a HMCR of 0.90 indicates that the HS algorithm will choose the decision variable value from historically stored values in the HM with an 90% probability or from the entire possible range with a (100–90)% probability. Every component obtained by the memory consideration is examined to determine whether it should be pitch-adjusted. This operation uses the PAR$\in [0,1]$ parameter, which is the rate of pitch adjustment as follows:

$$x'_i \leftarrow \begin{cases} Adjusting\ Pitch & With\ Probability\ PAR \\ Doing\ Nothing & With\ Probability\ (1-PAR) \end{cases}$$

The value of (1-PAR) sets the rate of doing nothing. If the pitch adjustment decision for x'_i is YES, x'_i is replaced as follow:

$$x'_i \leftarrow x'_i \pm rand \times bw$$

Where,

bw is an arbitrary distance bandwidth.

$rand$ is a random number between 0 and 1.

c. Update harmony memory

For each new value of harmony the value of objective function, $f(x')$ is calculated. If the new harmony vector is better than the worst harmony in the HM, the new harmony is included in the HM and the existing worst harmony is excluded from the HM.

d. Check stopping criterion

If the stopping criterion (maximum number of improvisations) is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated. Finally the best harmony memory vector is selected and is considered as best solution to the problem.

B. Improved Harmony Search Algorithm (IHSA)

This method HSA is developed by M. Mahdavi et al. 2007 [5]. In HSA there are few important parameter are there – HMCR, PAR, bw, but PAR and bw are very important parameters in fine-tuning of optimized solution vectors. The traditional HS algorithm uses fixed value for both PAR and bw. In the HS method PAR and bw values adjusted in Step 1 and cannot be changed during new generations. The main drawback of this method is that the number of iterations increases to find an optimal solution .To improve the performance of the HS algorithm and eliminate the drawbacks lies with fixed values of PAR and bw, IHSA uses variables PAR and bw in improvisation step (Step 3). PAR and bw change dynamically with generation number and expressed as follow also pseudo code for IHSA is shown in figure 3:

$$PAR\,(gn) = PAR_{min} + \frac{(PAR_{max} - PAR_{min})}{NI} \times gn,$$

Where,

PAR(gn) = Pitch Adjusting Rate for each generation

PARmin = Minimum Pitch Adjusting Rate

PARmax = Maximum Pitch Adjusting Rate

NI = Number of solution vector generation

gn = Generation Number

$$bw(gn) = bw_{max} \exp(c \,.\, gn)$$

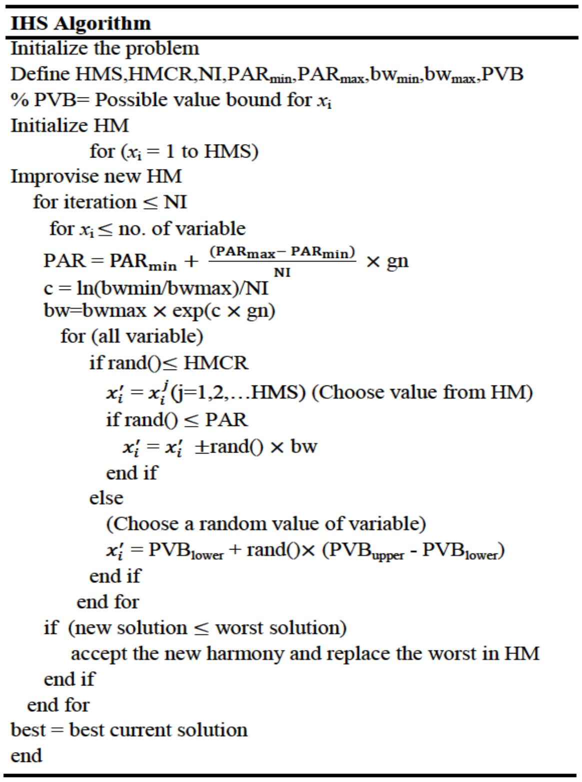
$$c = \frac{\ln\left(\frac{bw_{min}}{bw_{max}}\right)}{NI}$$

Where,

bw (gn) = Bandwidth for each generation

bw_{min} = Minimum bandwidth

bw_{max} = Maximum bandwidth



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IHS Algorithm
Initialize the problem
Define HMS,HMCR,NI,$PAR_{min}$,$PAR_{max}$,$bw_{min}$,$bw_{max}$,PVB
% PVB= Possible value bound for $x_i$
Initialize HM
        for ($x_i$ = 1 to HMS)
Improvise new HM
   for iteration ≤ NI
     for $x_i$ ≤ no. of variable
       $PAR = PAR_{min} + \frac{(PAR_{max} - PAR_{min})}{NI} \times gn$
       c = ln(bwmin/bwmax)/NI
       bw=bwmax × exp(c × gn)
         for (all variable)
            if rand()≤ HMCR
              $x_i' = x_i^j$ (j=1,2,…HMS) (Choose value from HM)
              if rand() ≤ PAR
                $x_i' = x_i'$ ±rand() × bw
              end if
            else
              (Choose a random value of variable)
              $x_i' = PVB_{lower} + rand() \times (PVB_{upper} - PVB_{lower})$
            end if
          end for
       if (new solution ≤ worst solution)
           accept the new harmony and replace the worst in HM
       end if
     end for
best = best current solution
end
```

Figure 3-Pseudo code of IHSA

C. Other Related Research on HSA

HSA is very effective method of optimization and so that many researchers are attracted to it. Now a days it is used to solve many optimization problems such as engineering and computer science problems. Consequently interest in

HSA led the researcher to improve and increase its performance in line with the requirements of problems that are solved. These improvements basically can be classified under two aspects:

(1) Improvements of HS in terms of parameter setting
(2) Improvements in terms of hybridizing of HS components with other meta-heuristic algorithms.

Improvements in terms of parameter setting many research have been done up till now. In HS there are three important parameters are there HMCR, PAR, and BW. Firstly M. Mahdavi et al (2007)[5] has developed a new method known as Improved harmony search algorithm in which PAR and BW have been modified (explained in section 2.2). Then after orman and Mahdavi (2008)[11] has developed Global harmony search (GHS) algorithm in which BW is modified using the PSO concept. Mukhopadhyay et al (2008)[28] proposed to modify bw by standard deviation method when GMCR is close to 1. Degertekin (2008) proposed a technique in which two times of HMS harmonies are generated but placed only the best HMS in to the initial HM. Chakraborty et al. (2009)[26] proposed new improvements to HS through inspiring the differential evolution (DE) mutation operator and replaces PAR with mutation strategy. Hasancebi et al (2009), saka and Hasancebi (2009) [29] proposed new adaptation for HS by modifying both HMCR and PAR dynamically during improvisation process. Wang and Huang (2010)[27] proposed dynamic selection of bw and PAR parameters. bw is os replaced by maximal and minimal values in HM, the PAR value is linearly decreased. Kattan et al (2010) [30] talks about stopping criteria, stopping criteria is replaced by best to worst harmony ratio in the current harmony memory. Al-Betar et al. (2010a) [25],Geem et al. (2005a) [31] proposed multi pitch adjusting rate strategy to modify PAR. Hadi Sarvari, Kamran Zamanifar (2012) [21] proposed improvement in HS by statistical analysis in which new harmony and bw is modified.

Hybridizing the HS is also well known technique to increase the performance of HSA by combining HS and other meta-heuristic algorithm. Orman and Mahdavi(2008) [11] uses PSO concept,in this method global best particle is incorporated by replacing the bw parameter and adding a randomly selected decision variables from best harmony vector in HM. Fesanghary et al. (2008) [15] proposed a new framework that combined HS with Sequential Quadratic Programming (SQP) to solve engineering optimization problems. Taherinejad (2009) [32] modified HS by inspiring the SA's way of cooling strategy and modified PAR value. Yildiz (2008) [33], Yildiz and Ozturk (2010) [34] proposed a new framework that combine HS with Taguchi method to improve the performance of HS. Similarly many other study has been done by combining HS with GA (Genetic Algorithm),FCM (Fuzzy c-means algorithm), CSA (Clonal selection algorithm),AIS (Artificial Immune System), DE (Differential Evolution), etc.

In all these methods the modification is done in step 3 of HS algorithm which is decision making or improvement step.

III. APPLICATIONS OF HSA AND IHSA

In this paper applications of Improved Harmony Search Algorithm is discussed related to engineering field, because HSA and IHSA are not much applied to engineering problems. So for increasing awareness and attracting researcher towards engineering applications here few applications are discussed.

A. Pressure Vessel Design

A cylindrical vessel is capped at both ends by hemispherical heads as shown in Figure 4[5]. The objective is to minimize the total cost, including the cost of material, forming and welding. There are four design variables: 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, witch are the available thickness of rolled steel plates, and R and L are continuous. Using the same notation given by Mahdavi [5], the problem can be stated as follows:

Minimize,

$$f(x)=0.6224\, x_1 x_3 x_4 + 1.778 x_3^2 x_2 + 3.16 x_4 x_1^2 + 19.84 x_3 x_1^2$$

Subject to,

$$g_1 = -x_1 + 0.0193\, x_3 \leq 0$$

$$g_2 = -x_2 + 0.00954\, x_3 \leq 0$$

$$g_3 = -\pi x_3^2 x_4 - \frac{4}{3} \pi x_3^3 + 1296000 \leq 0$$

$$g_4 = x_4 - 240 \leq 0$$

$$g_5 = 1.1 - x_1 \leq 0$$

$$g_6 = 0.6 - x_2 \leq 0$$

By applying IHSA to above problem Mahdavi [5] found the following results which are comparable with other methods and global solutions for four decision variables can be found out. Results are shown in table 1[5].

B. Minimization of Weight of spring

It consists of minimizing the weight of a tension/compression spring subject to constraints on shear stress, surge frequency and minimum deflection as shown in Figure 5[5]. The design variables are the wire diameter d $(=x_1)$, the mean coil diameter D $(=x_2)$ and the number of active coils N$(=x_3)$. The problem can be stated as:

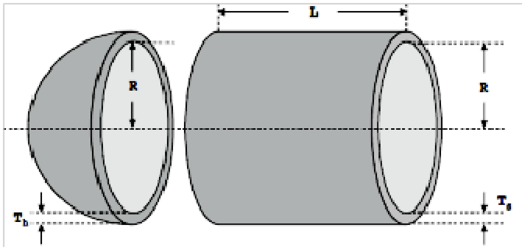


Fig 4-Pressure vessel problem

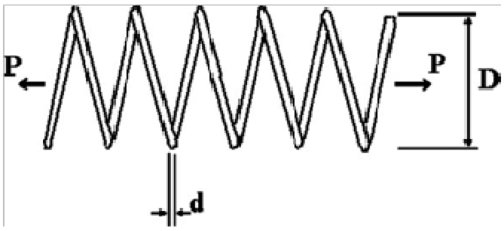


Fig 5-Spring Design problem

Minimize: $f(x) = (x_3+2)x_2x_1^2$

$$g_1(x) = 1 - \frac{x_3x_2^3}{71785x_1^4} \leq 0$$

$$g_2(x) = \frac{4x_2^2 - x_1x_2}{12566\,(x_2x_1^3 - x_1^4)} + \frac{1}{5108x_1^2} - 1 \leq 0$$

$$g_3(x) = 1 - \frac{140.45x_1}{x_2^2x_3} \leq 0$$

$$g_4(x) = \frac{x_2 + x_1}{1.5} - 1 \leq 0$$

Results obtained by applying IHSA to this problem are shown in table 2[5]:

Table 1: Pressure Vessel Design

Optimum Design Variable	HSA	IHSA
x_1	1.125	1.125
x_2	0.625	0.625
x_3	58.2789	58.29015
x_4	43.7549	43.69268
$f(x)$	7198.433	7197.730

Table 2: Spring design for minimum weight

Design Variable	IHSA
x_1	0.05115438
x_2	0.34987116
x_3	12.0764321
$f(x)$	0.0126706

C. Welded Beam Design

The welded beam structure, shown in Figure 6[5], is a practical design problem that has been often used as a benchmark for testing different optimization methods. The objective is to find the minimum fabricating cost of the welded beam subject to constraints on shear stress (τ), bending stress (σ), buckling load (P_c), end deflection (δ), and side constraint. There are four design variables: $h(=x_1), l(=x_2), t(=x_3),\ and\ b(=x_4)$. The mathematical formulation of the objective function $f(x)$, which is the total fabricating cost mainly comprised of the set-up, welding labor, and material costs, is as follows:

Minimum cost, $f(x) = 1.1047x_1^2x_2 + 0.04811x_3x_4(14.0 + x_2)$

$g_1 = \tau(x) - \tau_{max} \leq 0$

$g_2 = \sigma(x) - \sigma_{max} \leq 0$

$g_3 = x_1 - x_4 \leq 0$

$g_4 = \delta(x) - \delta_{max} \leq 0$

$g_5 = P - P_c(x) \leq 0$

$0.125 \leq x_1 \leq 0, 0.1 \leq x_2, x_3 \leq 10, 0.1 \leq x_4 \leq 5$

Where,

$$\tau(x) = \sqrt{(\tau')^2 + 2\tau'\tau'' \frac{x_2}{2R} + (\tau'')^2}$$

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 1, January 2013

$$\tau' = \frac{P}{\sqrt{2}x_1x_2}, \tau'' = \frac{MR}{J}, M = P\left(L + \frac{x_2}{2}\right),$$

$$R = \sqrt{\frac{x_2^2}{4} + \left(\frac{x_1 + x_3}{2}\right)^2}$$

$$J = 2\left\{\sqrt{2}x_1x_2\left[\frac{x_2^2}{4} + \left(\frac{x_1 + x_3}{2}\right)^2\right]\right\}$$

$$\sigma(x) = \frac{6PL}{x_4x_3^2}, \delta(x) = \frac{6PL^3}{Ex_3^2x_4},$$

$$P_c(x) = \frac{4.013E\sqrt{x_3^2x_4^6/36}}{L^2}\left(1 - \frac{x_3}{2L}\sqrt{\frac{E}{4G}}\right)$$

P=6000lb, L=14in., δ_{max}=0.25in., E=30×10^6psi, τ_{max}=13,600psi, σ_{max}=30,000psi.
The solution of above problem is shown in table 3[5]:

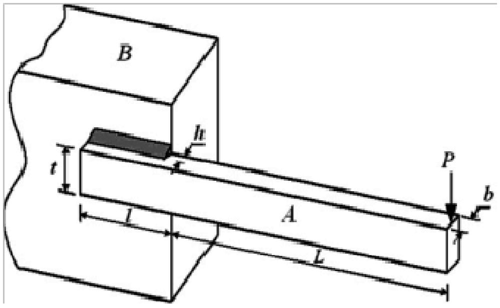


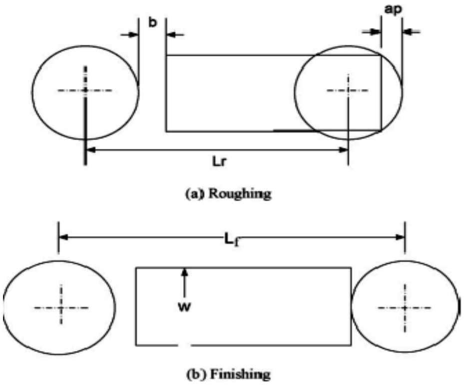
Fig 6-Welded beam design

Optimum Design Variable	HSA	IHSA
x_1	0.2442	0.20573
x_2	6.2231	3.47049
x_3	8.2915	9.03662
x_4	0.2443	0.20573
$f(x)$	2.3807	1.7248

Table 3: Welded Beam Design

D. Multi passes face milling operation [16]

Here the machining operation is divided into roughing and finishing operations shown in figure 7(a) & (b)[16]. The objective is to find the minimum production cost and the corresponding cutting parameters [16]. Maximum number of sections to cut is 6. The total depth is 8mm and the cost values are presented for rough passes varying from 1mm to 4mm in steps of 1mm and from 1mm to 2mm in steps of 1mm for finish pass.



(a) Roughing

(b) Finishing

Fig 7(a) : Diagram of face milling operation

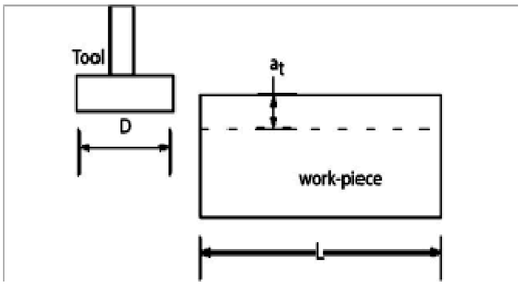


Fig 7(b) : Diagram of face milling operation

In rough machining, the length of the cutter travel is given by:

$$Lr = L + a_p + b$$

In finish machining,

$$L_f = L + D + b$$

Where,

L= Length of w/p

a_p = Approach distance= $\left[\frac{D}{2} - \sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{w}{2}\right)^2}\right]$

b = Arbitrary distance to avoid damage
D = Diameter of tool
w = Width of w/p

The total production cost (Ut),

$$U_t = U_f + \sum_{i=1}^{n} U_{ri} + A_4$$

Where,

$\text{Cost of tool preparation} = A_4 =$ $k_o t_p$

Uf is the cost of the finishing pass and Uri is the cost of the ith roughing pass.

The cost of a single pass (U) is given by,

$$U = k_0 t_m + (k_t z)\frac{t_m}{T_R} + (k_0 t)\frac{z t_e}{T_R} + k_0(Lh_1 + h_2)$$

Where,

$$t_m = \frac{L_t}{zsN}$$

Constraints:

1. Tool Life(T):

$$T^m = \frac{c_v k_v}{V a^{x_v} s^{y_v}} \frac{D^{q_v}}{w^{t_v} z^{p_v}} - - - - - - - - (1)$$

Where, V = Cutting speed, D = Diameter of cutter, W = width of w/p
a = Depth of cut, Z = number of Teeth of cutter

2. Available speed:

$$Vmin \leq V \leq Vmax - - - - - - - - -(2)$$

Minimum and Maximum Cutting speed = V_{min} = V_{max}

3. Depth of cut (a):

$$a_{min} \leq a \leq a_{max} - - - - - - - - - - - - (3)$$

4. Feed(s):

$$s_{min} \leq s \leq s_{max}$$

Surface finish = $R_a = \frac{0.0321 s^2}{r_\varepsilon}$

Where, $r_\varepsilon = Nose\ radius$

Combining both equations:

$$s_{min} \leq s \leq \min\left(s_{max}, \left(\frac{R_a r_\varepsilon}{0.0321}\right)^{1/2}\right) - - - - - (4)$$

5. Cutting Force (F):

$$F_z = C_F a^{x_F} s^{y_F} \left[\frac{B^{t_F} z^{p_F}}{D^{q_F} {n_s}^{w_F}}\right] K_F - - - - - - - - (5)$$

C_F and K_F= Constant with regard to tool and w/p

6. Cutting Power (P):

Mean value of power is given by,

$$P_m \geq \frac{F_z V}{6120} - - - - - - - - - - - - - - (6)$$

Where, P_m = Motor power

7. Stock removing:

$$Total\ Depth\ of\ cut = a_t = a_f + \sum_{i=1}^{n} a_{ri} ------(7)$$

a_f =depth of cut in finish pass
a_{ri} =Depth of the ith pass in roughing
Equations 1-7 are constraints for the problem. Results are shown in table 4[16].

Table 4: Result for multi pass milling (a_t=8)

Pass no	a (mm)	S (mm/tooth)	V (m/min)	R_a (μm)	P (KW)	F (N)	Cost ($)
1	3	0.453	60.75	6.59	8	8000	0.4446
2	3	0.453	60.75	6.59	8	8000	0.4446
3	2	0.279	119.22	2.50	7.7	3879	0.5047
Total							1.3939

E. Optimization of Plate-fin heat exchanger [17]

A gas-to-air single pass cross flow heat exchanger having a heat duty of 1069.8 kW needs to be designed to achieve minimum heat transfer area and minimum total pressure drop separately. The maximum flow length and no flow length, Lc, of the heat exchanger are 1 m and 1.5 m respectively. The operating conditions are listed in Table 5[17]. In this study, a total number of seven parameters, namely the hot flow length (La), the cold flow length (Lb), the number of hot side layers (Na), the fin frequency (n), the fin thickness (t), the fin height (H), and the fin strip length (lf) are considered as the optimization variables. All variables except the number of hot side layers are continuous. The thickness of the plate, tp, is considered to be constant at 0.5 mm and is not to be optimized. The variation ranges of the variables are shown in Table 6[17].

Table 5: Operating parameters selected for the case study

Parameters	Hot Side	Cold Side
Mass Flow rate, m(kg/s)	1.66	2
Inlet temperature, T (°C)	900	200
Specific heat, Cp (J/kg K)	1122	1073
Density, ρ (kg/m3)	0.6296	0.9638
Dynamic viscosity, μ (Ns/m^2)	401E-7	336E-7
Prandtl number, Pr	0.731	0.694
Maximum pressure drop, ΔP (N/m^2)	9.50	8.00

Table 6: Variation ranges of design parameters

Parameter	Min	Max
Hot flow length (La) (m)	0.1	1
Cold flow length (Lb) (m)	0.1	1
Fin height (H) (mm)	2.0	10
Fin thickness (t) (mm)	0.1	0.2
Fin frequency (n) (m_1)	100	1000
Fin offset length (lf) (mm)	1	10
Number of hot side layers (Na)	1	200

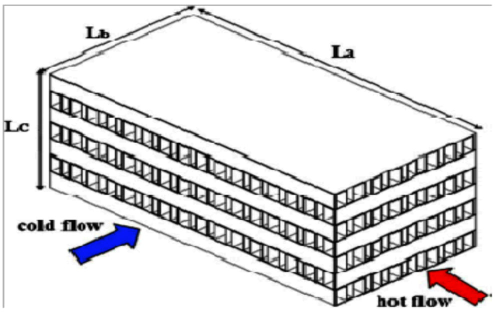


Fig 8(a): A schematic drawing of PFHE

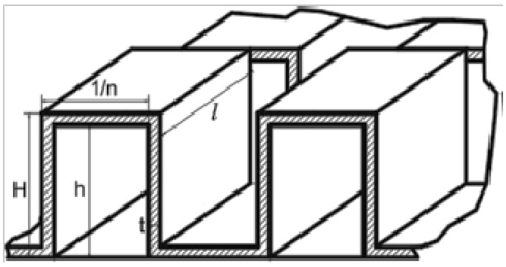


Fig 8(b): A drawing of an offset strip fin

In this work, the optimization targets two single-objective functions. The first is minimization of the heat transfer area, which is mainly associated with the capital cost of the heat exchanger, and the other is minimization of the total pressure drop, which represents the operating cost. In figure 8(a) and (b)[17] schematic drawing of PFHE is shown.

The total heat transfer area is given by:

$$A_{HT} = A_a + A_b$$

Where, Heat transfer is on both side:

$$A_a = L_a L_b N_a [1 + 2n_a (H_a - t_a)]$$

$$A_b = L_a L_b N_a [1 + 2n_b (H_b - t_b)]$$

The total pressure drop is calculated as follows.

$$f(x) = \frac{\Delta P_a}{P_{a,max}} + \frac{\Delta P_b}{P_{b,max}}$$

Constraints:

Frictional pressure drop:

$$\Delta P_a = \frac{2 f_a L_a G_a{}^2}{\rho_a D_{h,a}}$$

$$\Delta P_b = \frac{2 f_b L_b G_b{}^2}{\rho_b D_{h,b}}$$

Result of above study is shown in table 7 and table 8.

Table 7: Results for minimum heat transfer area.

Optimum design variable	IHSA
Side a length (La) (m)	0.20
Side b length (Lb) (m)	0.21
Fin height (H) (mm)	6.7
Fin thickness (t) (mm)	0.10
Fin frequency (n) (m^{-1})	999.8
Lance length (lfa) (mm)	1.7
Number of hot side layers (Na)	87
Heat transfer area (m^2)	109.62

Table 8: Optimized results for minimum pressure drop

Optimum design variable	IHSA
Side a length (La) (m)	1.0
Side b length (Lb) (m)	1.0
Fin height (H) (mm)	10
Fin thickness (t) (mm)	0.1
Fin frequency (n) (m^{-1})	211
Lance length (lfa) (mm)	10
Number of hot side layers (Na)	71
Total pressure drop	0.054

IV. CONCLUSION

Harmony search algorithm is a meta-heuristic algorithm which is very important tool in optimization problems. It has been applied to diversified problems in past years and results are very effective compare to other meta-heuristic algorithms. Also HSA is modified and hybridized by different methods. Here one modified algorithm IHSA has been discussed with its applications. HAS is very flexible to implement easy to apply. In IHSA few drawbacks of HSA are removed and so that performance of HSA is improved. Also previously it is applied to many different areas of discipline but in mechanical engineering its applications are very few. Few of applications are discussed in this paper and author hope that this paper will inspire researchers to work on HSA by applying in mechanical engineering area.

ACKNOWLEDGEMENT

Many thanks to my project guide for his valuable comments that helped to improve this paper. During this study the resources of Sankalchand Patel college of Engineering, Visnagar helped for improving the quality of the study.

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