

HARMONY SEARCH ALGORITHM FOR OPTIMAL DESIGN OF WATER SUPPLY NETWORKS

^{1,2}LI YANG, ¹JINXUE SUI, ¹ZHEN HUA

¹School of Information and Electronic Engineering, Shandong Institute of Business and Technology, Yantai 264005, Shandong, China

²Department of Control Engineering, Naval Aeronautical Engineering University, Yantai 264001, Shandong, China

ABSTRACT

Optimization design of water supply pipe network is important with the development of economy and the increasingly fast urbanization process. Harmony search algorithm for the optimal design of water supply networks provides a better nonlinear optimization method. The improved strategy of the dynamic harmony memory size is proposed, through the optimization computation to water supply pipe network, compared with other algorithms, the improved HS algorithm in network optimization design problem has its superiority, its high speed, high efficiency, good convergence, can guarantee the stability of the global search optimization, and can provide the optimal design scheme.

Keywords: *Water Supply Networks, Harmony Search, Optimization Design, Dynamic Adaptive*

1. INTRODUCTION

With the development of economy and the increasingly fast urbanization process, on the one hand, large quantities of supplies and population to the city together, this put forward higher requirements to the city water supply system; on the other hand, city water supply shortage is becoming more and more serious. According to the Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) report, in 2010, about 400 cities is suffering a desperate shortage of water, water shortage, amounted to 1600 cubic meters per day, the annual economic loss caused by water shortage in industry more than 230000000000 yuan. Lack of water will not only affect the industrial and agricultural production and people's daily life, and may endanger the safety of the city. With the development of the national economy growing rapidly, a sharp increase in the amount, China is expected in 2030 to appear water peak.

The water shortage means we should build on the existing foundation to save water resource, especially water supply in the densely populated city. City water supply pipe network project cost account for about 50%-80% of the entire water supply project total investment. Under the conditions of the use requirements, the minimum cost is the key in the engineering design. Water

supply project optimization design can not only reduce the investment, but also to the pump efficiency, saving water resources and so on. So it is necessary to optimize the design of water supply pipe network.

Network optimization takes the main economical efficiency as objective function, to ensure the required water pressure, under the reliable condition for the optimal economic. In the optimization of network to solve the model is relatively difficult, has gone through the linear programming model, nonlinear programming model, dynamic programming model, neural network, genetic algorithm and so on[1-4].

Harmony search algorithm for the optimal design of water supply networks provides a better nonlinear optimization method. The algorithm was proposed by Geem in 2001, its basic thought originated from the simulation that music by harmonic notes to achieve optimal performance process: Music coordination process can be regarded as the optimization process, each player can be regarded as the decision variable, musical instrument tuning range can be seen as a decision variable adjustment range, good harmonic tones stored in memory in a musician can be regarded as a better solution stored in memory. At present already in the structure design, traffic path and environment parameter correction engineering has cited [5-10].

2. IMPROVED HARMONY SEARCH (IHS) ALGORITHM

2.1 The Original Harmony Search Algorithm

Harmony Search (HS) is a heuristic optimization algorithm. It was conceptualized from the musical process of searching for a ‘perfect state’ of harmony, namely the people seeks a best state (fantastic harmony) in the esthetic process through reasonable matching several kinds of musical instrument, just as the optimization algorithm seeks a best state (global optimum) determined by

evaluating the objective function. Aesthetic estimation is performed by the set of pitches played by each instrument, just as the objective function evaluation is performed by the set of values assigned by each decision variable. The harmony quality is enhanced practice after practice, just as the solution quality is enhanced iteration by iteration.

It has been shown that HS outperforms various optimization methods in many optimization problems. HS mimics the improvisation of music players for searching the better harmony. The HS step is shown in Fig. 1.

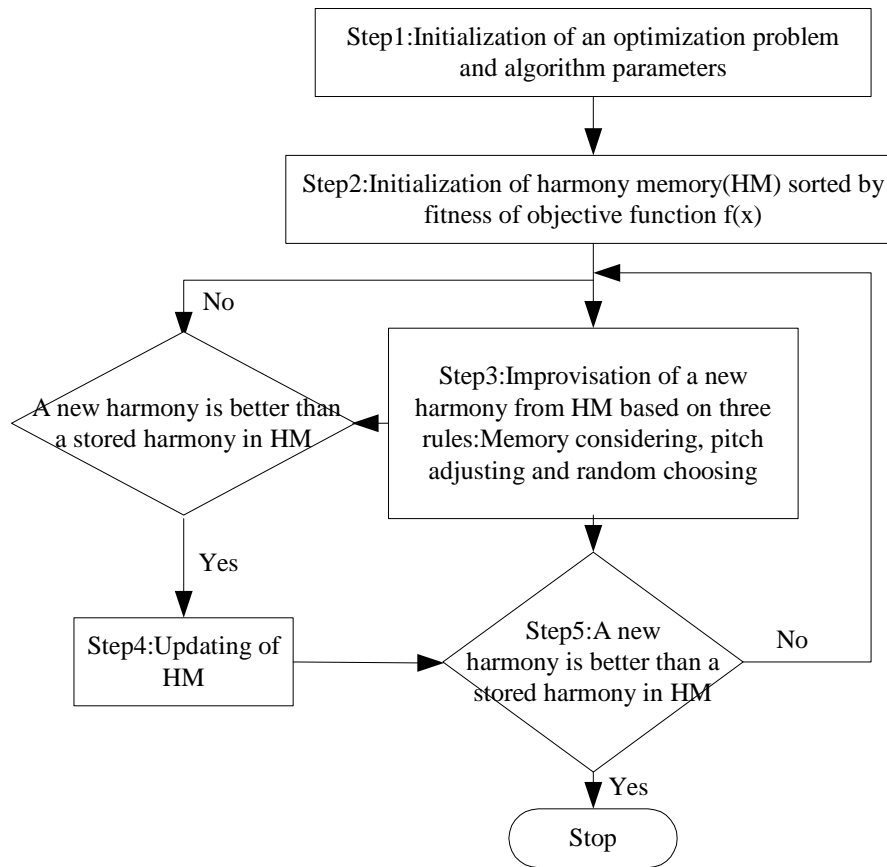


Figure 1: Optimization Steps Of The Harmony Search Algorithm

- (1) Initializing the problem and algorithm parameters including a representation of solution vectors to the problem.
- (2) Creating an initial harmony memory (HM) of candidate solutions as a solution vector.
- (3) Improvising a new harmony from HM.
- (4) Updating the harmony memory.

- (5) And, finally, checking the stopping criterion.

HS manages the harmony memory vectors of harmonies in which each harmony represents a potential solution to the given problem. It executes an essentially blind search in complex search space. To be successful, HS must strike a balance between exploitation and exploration.



HS has four main parameters that direct the search toward the most favorable areas of the search space. These parameters are:

- Harmony memory size (HMS) represents the total number of harmonies in the HM.
- Harmony memory consideration rate (HMCR) represents the probability of picking up values from HM to the variables in the solution vector.
- Random selection rate (RSR) represents the probability of randomly choosing feasible values from the range of all possible values to the variables in the solution vector.
- Pitch adjusting rate (PAR) represents the probability of further adjusting the pitch with neighboring pitches.

In each cycle or 'improvisation', each harmony is evaluated to determine its relative fitness within the harmony memory vectors; a new harmony is retained via each improvisation process. HMCR and PAR are applied to the HM in each improvisation process.

After the improvisation of the new Harmony is completed, it is evaluated by its objective function (fitness function). If the value of its objective function is better than the value of the objective function of the worst harmony in the HM, the new harmony is included in the HM and the existing worst harmony is excluded from the HM. Consequently, the vectors are sorted out based on their fitness functions. Then, the cycle repeats itself with a new harmony. After a varying number of improvisations, the algorithm converges to the best harmony, which represents a quasi-optimal or optimal solution to the given problem.

2.2 The Improved Harmony Search (IHS)

In general, the size of memory database is larger, the capability to find the globally optimal region is stronger, but because HS is starting from multiple points, with the increase of the memory storage, computation will be bigger, which affects the final search speed to optimal solution. Basic harmony search algorithm memory size is a fixed value, in this paper proposed the improved strategy of the dynamic harmony memory size, is called the improved harmony search algorithm (IHS). In the prophase, harmony memory size of M is larger, with the number of iterations increases, memory size decreases, down to a predetermined size Q (Q<M).

IHS flow chart and design steps:

Step1: Random initialization HM, its size is M;

Step2: Improved harmony search

Step2.1: Generates a random number rand1, if rand1<HMCR, then the harmony memory is selected within each musical tone, or in the musical tone range selection;

Step2.2 Generates a random number rand2, if rand2<PAR, the tone disturbance, or to maintain the original tone;

Step2.3: Through all the musical instruments; otherwise the implementation of step2.1

Step2.4: Generates N group of the new harmony, otherwise the implementation of step2.1;

Step2.5 generates a new memory HM, the size is N+M;

Step2.6: In M+N group, take out evaluation of the better value of the M group to update HM;

Step2.7: Calculating the evaluation value of the various HM;

Step2.8: If M>Q, executing step2.9, otherwise executing step2.10;

Step2.9: The memory size is M=M-1;

Step2.10: Judging whether conform to the stopping criterion; otherwise executing step2;

Step3: Stops search, output the most beautiful harmonies and evaluation value.

2.3 Improved Algorithms Test

Choosing Rastrigrin, Griewank, Rosenbrock, Ackley functions as optimization test functions, let HMCR=0.95, PAR=0.1, M=10, HS and IHS search algorithm through iterative algorithm, the number of iterations results as shown in Table 1, the improved harmony search convergence rate decreased obviously:

Table 1: Comparison Of 4 Different Functions Optimization

	Rastrigrin	Griewank	Rosenbrock	Ackley
HS	1237	236	421	2185
IHS	306	28	36	163

Taking the Ackley function as an example to several optimization

$$\text{tests, } f(x) = \sum_{i=1}^m (100(x_{i+1}^2 - x_i)^2 + (1 - x_i)^2) \quad ,$$

$x_i \in [-2.048, 2.048]$, the iterative convergence curve as shown in figure 2, and the improved algorithm significantly faster convergence rate.

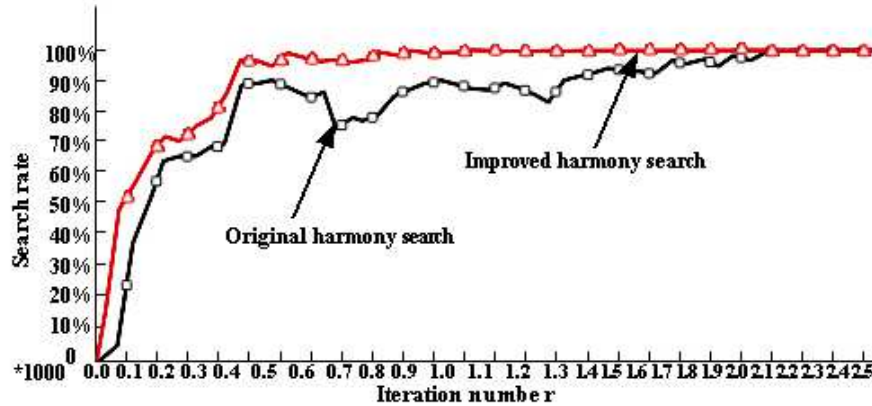


Figure 2: The Convergence Curve Of The Harmony Search

3. IMPROVED HARMONY SEARCH ALGORITHM FOR OPTIMAL DESIGN OF WATER SUPPLY NETWORKS

3.1 The Original Harmony Search Algorithm

In the type, a and b are the coefficient and index of the unit length of pipe cost formula; D_{ij}^a is pipe diameter; E is energy charge, fen/kWh; Q is the flow of the input system in pipeline, L/s ; η is the operating efficiency of pump station, usually 0.55~0.85; p is the annual depreciation and repair costs, %; l_{ij} is the pipeline length, m; t is the investment repayment period, a; β is the variation coefficient of water supply energy; ρ is the water density, $\rho = 1kg/L$; g is the gravity acceleration value, $g = 9.81m/s^2$; H_0 is the static lift pump, m; $\sum h_{ij}$ is the water head loss from the pipeline starting point to the control point of any pipeline, m.

3.2 Constraint Condition

The objective function of water supply pipe network optimization design is built based on a

series of constraint equation, should satisfy the following conditions:

(1) Node flow equation

$$\sum Aq + Q = 0 \tag{1}$$

(2) Loop energy equations

$$Lh_k = 0 \tag{2}$$

In the type: L is the circuit matrix; h_k is the column vector of the pipe head loss.

(3) Pump head

$$H_p = H_0 + \sum h_y \tag{3}$$

In the type, H_p is a pump head, H_0 is a control point water pressure.

(4) Nodal pressure constraint

$$H_{\min} \leq H \leq H_{\max} \tag{4}$$

In the type, H_{\min} and H_{\max} respectively is the minimum and maximum pressure values that the node requests.

(5) Pipe velocity constraint

$$v \leq v_{\max} \tag{5}$$

In the type, v_{\max} is the maximum of the pipeline flow.

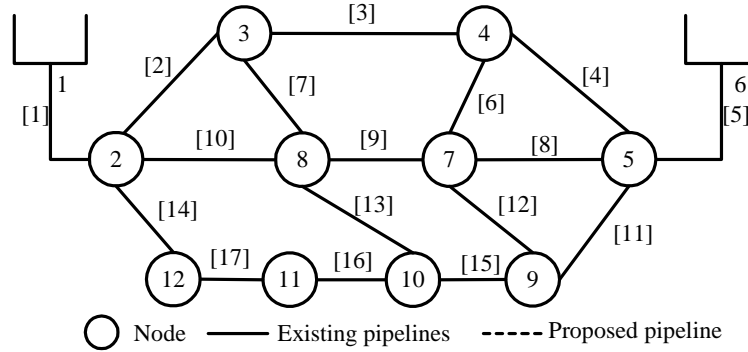


Figure 3: Network Layout Example Diagram

3.3 Simulation Example[1]

Using the established target mathematical model of optimization design and the improved harmony search algorithm, as shown in Figure 3 network to optimize the design, including pipeline and a water tower base in the plains, the gravity water supply mode, no power costs, two towers of initial water level were set to 26m, pipe made of plastic pipe, pipe head loss using the sea had William formula. Unit cost in different diameter length shown in Table 2, multiple working conditions of each node, the node with the elevation of the ground water, guarantee the water table 2 pipe sections 1 to 8 of the diameter of optimization decision variables, of which 1 to 3 to consider whether the renovation and expansion of the existing pipe, 4 to 8 for the pipe section. Water service condition, node flow and ensure the elevation of the ground water is

shown in table 3, Pipe unit length cost is shown in table 4.

This example uses the gravity water supply pipe network, the objective function is simplified, only the variable, and introducing the hydraulic related penalty function, the objective function can be modified for:

$$Min \text{ cost} = \begin{cases} \sum_{i=1}^N C_i \times L_i & (\text{Satisfy pressure constraint}) \\ \sum_{i=1}^N C_i \times L_i + P \times \Delta H_{\max} & (\text{Otherwise}) \end{cases}$$

In the type, $i = 1, 2, \dots, N$, N is the number of segments, pipe, C_i is the cost of the i th unit pipe length, L_i is the length of the i th unit pip, P is the punishment factor (yuan/m), ΔH_{\max} is difference between the actual pressure and the normal hydrostatic pressure.

Table 2 : The Length, Diameter And Hazen- Williams Coefficient

Pipe Number	Starting point	End point	Length/m	Pipe diameter	H-W coefficient
[1]	1	2	4850	0.40	80
[2]	2	3	1500	0.30	100
[3]	3	4	1200	0.25	100
[4]	4	5	1200	0.30	100
[5]	5	6	5650	0.35	80
[6]	4	7	1800	0.20	100
[7]	3	8	1900	0.20	100
[8]	4	7	1880	0.30	100
[9]	7	8	1100	0.25	100
[10]	2	8	1600	0.30	80
[11]	5	9	1300	0.30	100
[12]	7	9	1800	0.25	100
[13]	8	10	1820	determined	120
[14]	2	12	1000	determined	120
[15]	9	10	1900	determined	120
[16]	10	11	1900	determined	120
[17]	11	12	1900	determined	120



Table 3 : Water Service Condition

Pipe Number	Starting point	Water service condition 1		Water service condition 2		Water service condition 3	
		Node flow (L/s)	Pressure (m)	Node flow (L/s)	Pressure (m)	Node flow (L/s)	Pressure (m)
1	61.0	0	0	0	0	0	0
2	23.5	42.0	15.0	42.0	15.0	42.0	15.0
3	19.0	42.0	15.0	42.0	15.0	42.0	15.0
4	22.0	12.7	15.0	12.7	15.0	12.7	15.0
5	20.5	42.0	15.0	42.0	15.0	42.0	15.0
6	61.0	0	0	0	0	0	0
7	21.4	13.5	15.0	13.5	15.0	13.5	15.0
8	19.6	12.7	15.0	52.7	15.0	12.7	15.0
9	21.0	12.7	15.0	12.7	15.0	12.7	15.0
10	21.4	64.0	15.0	64.0	15.0	64.0	15.0
11	22.6	21.0	15.0	21.0	15.0	51.0	10.0
12	24.1	12.7	15.0	12.7	15.0	12.7	15.0

Table 4 : Pipe Unit Length Cost

Pipe diameter (mm)	200	250	300	350	400	450	500	600
Cost (yuan/m)	283.06	389.28	538.28	626.57	729.69	832.42	958.50	1214.10

Harmony memory search of HMS is 50, $HMCR_{max}$ is 0.96, $HMCR_{min}$ is 0.88, PAR_{max} is 0.25, PAR_{min} is 0.20, dynamic adaptive search probability is 0.8, the iteration number is 3000, and the penalty factor P is 500000. Repeat computation is 20, achieved the same optimal solutions, and explained that the

improved HS algorithm can get global optimal solution. The improved harmony search algorithm for optimal design of investment project is shown in Table 4.

From Table 5 shows, the objective function from 8709752.4 of HS to 8645468.1 of IHS, Optimization effect is improved obviously.

Table 5 : Improved Harmony Search Algorithm For Optimal Design Of Investment Project

	Total investment (yuan)	Pipe 1 (mm)	Pipe 2 (mm)	Pipe 3 (mm)	Pipe 4 (mm)	Pipe 5 (mm)	Pipe 6 (mm)	Pipe 7 (mm)	Pipe 8 (mm)
IHS	8645468.1	Changed to 500	hold	hold	200	400	200	300	350
HS	8709752.4	Changed to 500	hold	hold	200	350	200	350	350

4. CONCLUSIONS

Through the optimization computation, compared with other algorithms, the improved HS algorithm in network optimization design problem has its superiority, its high speed, high efficiency, good convergence, can guarantee the stability of the global search optimization, and can provide the optimal design scheme. Therefore, the improved HS algorithm can have effect for network optimization problem, and has good application prospect.

ACKNOWLEDGEMENTS

This work is supported by NSF 60970105; education department S&T plan J08LJ70 and NSF

of Shandong Province ZR2010FL015 and ZR2010FL021; Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) Development science and technology project 2010-K9-26; Department of Housing and Urban-Rural Development of Shandong province Development science and technology project 2011YK059.

REFERENCES:

[1] Lv Jian, Jia Yanbing, "Optimal Design of Water Distribution System by Genetic Algorithm", *Water and wastewater engineering*, Vol.27, No. 5, 2010,pp. 36-39.



- [2] Zong Woo Geem, "Harmony search optimization to the pump-included water distribution network design", *Civil Engineering and Environmental Systems*, Vol. 26, No. 3, 2009, pp. 211-221.
- [3] Xin Kunlun, Liu Suiqing, Tao Tao, Li Shuping, "Application of Pseudo-Parallel Genetic Algorithm in Optimal Operation on Water Supply Network", *Journal of Tongji University*, Vol. 34, No. 12, 2006, pp. 1662-1667.
- [4] Zhuang Baoyu, Yang Yufei, Zhao Xin-hua, "Optimization of Water Distribution System Based on Improved Shuffled Frog Leaping Algorithm", *China water and wastewater*, Vol. 27, No. 9, 2011, pp. 45-49.
- [5] Z. Geem, J. Kim, G. Loganathan, "A new heuristic optimization algorithm: harmony search", *Simulation*, Vol. 76, No. 2, 2001, pp. 60-68.
- [6] Z.Geem, "Optimal cost design of water distribution networks using harmony search", *Engineering Optimization*, Vol. 38, No. 3, 2006, pp. 259-280.
- [7] A.Vasebi, M.Fesanghary, S.M.T.Bathae, "Combined heat and power economic dispatch by harmony search algorithm", *Electrical Power and Energy Systems*, Vol. 29, No. 10, 2007, pp. 713-719.
- [8] K.Lee,Z.Geem, "A new meta-heuristic algorithm for continuous engineering optimization: harmony search theory and practice", *Computer Methods in Applied Mechanics and Engineering*, Vol. 194, No. 36, 2007, pp. 3902-3933.
- [9] Mahamed G.H.Omran, Mehrdad Mahdavi, "Global-best harmony search", *Applied Mathematics and Computation*, Vol. 198, No. 2, 2008, pp. 643-656.
- [10] M.Mahdavi, M.Fesanghary, E.Damangir, "An improved harmony search algorithm for solving optimization problems", *Applied Mathematics and Computation*, Vol. 188, No. 2, 2007, pp. 1567-1579.