Applied Mechanics and Materials
ISSN: 1662-7482, Vol. 734, pp 530-533
doi:10.4028/www.scientific.net/AMM.734.530

Submitted: 2014-11-11
Accepted: 2014-11-27
Online: 2015-02-25

The study of Ant Colony Algorithm in Hydraulic Breakdown Diagnosis

Jianjun Deng [1,a], Yanbin Li [2,b] and Lin Zhang [3,c]

[1] Air Defense and Anti-missile Institute, Air Force Engineering University, Xi'an, 710051, China

[2] Air Defense and Anti-missile Institute, Air Force Engineering University, Xi'an, 710051, China

[3] Air Defense and Anti-missile Institute, Air Force Engineering University, Xi'an, 710051, China

[a]jj_dd_yy@163.com, [b]yuanchen4@sina.com, [c]kjddlz@163.com

Keywords: Ant Colony Algorithm. breakdown diagnosis. hydraulic system

Abstract. A kind of breakdown diagnosis algorithm was proposed based on Ant colony algorithm. The problem of fault identification and classification was translated to a constrained optimized clustering problem under certain conditions in this algorithm. It was applied to the process of fault diagnosis of a hydraulic system. The results show the algorithm is valid and reasonable.

Introduction

Ant colony algorithm is a new biological algorithm from mimic the behavior of ant colony, proposed by Italy scholar M. Dorigo in 1990's and first used to address the Traveling Salesman Problem (TSP). This optimization algorithm, which has the characters of positive feedback and parallel processing, is inspired by the ants' foraging behavior. Ant colony algorithm is a kind of random search algorithm, it is same to other simulated evolutionary algorithm through the candidate solution composition group to seek the optimal solution in the course of evolution. The ant colony optimization algorithm has been widely studied and many important results have been obtained. It applied in assignment problem, Job-shop problem, Vehicle routing problem, Graph-coloring problem and so on. The advantage has showed in solving complex optimization problems (especially in discrete optimization problem), then it is a new type of perspective development algorithm[1].

Fault accurate classification is the key for hydraulic system diagnosis of hydraulic system. In most instances, the judgment of the hydraulic system breakdown is practiced based on human's experience. The algorithm in this paper is applied to identification and classification of hydraulic system fault. We can introduce different judgment criteria to adapt different problem. Specially, the algorithm can widely be used in pattern recognition and cluster analysis[2].

Principle of ant colony algorithm

Due to the high social organization, ants can find a short path even the nearest one between their nest and food sources in a shortest time [3][4]. Research suggests that as ants forage for food, every ant give off a chemical substance called pheromone, which is used as a medium for communication and an indirect form of memory of previously found solutions. When ants travel, they can perceive the pheromone and its intensity. Thus the pheromone can be a moving guidance for ants. Ants can move towards the direction with high pheromone intensity. So the ant colonies foraging for food presents to be an information-positive-feedback phenomenon: the more pheromone there is, the more opportunity there is for the ant to choose the path. Ants choose the shortest path and find food by this kind of information communicating, identify a new short path, In the end, the nearest path is found by cooperation.

The principle of typical ant colony system is as follows. Some artificial ants are generated and initially locate on n nodes according to uniform randomization rule. Each ant has a path list and a taboo list to record the nodes on the graph that the ant has visited. By applying a stochastic greedy rule known as state transition rule again and again, each ant will build a tour. In the process of building tour, each ant changes the amount of pheromone on the edges that it has visited by applying local update rule. When all ants return to the start nodes, the amount of pheromone on edges is updated again by applying global update rule. During the tours construction, the ants apply state transition rule which makes use of both heuristic information and pheromone information to choose the next edge to travel from its current node. Repeat the process until the system finds the optimal path.

Fault identification algorithm based on ant colony algorithm

When any complex system failure occurs, its output are different from symptoms of normal state, the different symptoms are corresponding to different fault reason, so knowledge acquisition in fault diagnosis could translate into cluster problem in Euclidean.

Neighbor function criteria. Only using the sample distance as classification index, sample often are classed in error. It can make misjudgment of fault. We can use neighbor function criteria to solve the cluster problem.

Any two sample in data set y_i, y_j, if y_j is a neighbor of y_i, sorted by distance size, y_j is I th neighbor in all neighbor of y_i, then define I as neighbor coefficient for y_j to y_i. If y_i is a neighbor of y_j, y_i is K th neighbor in all neighbor of y_j, and then define K as neighbor coefficient for y_i to y_j. While distance between y_i and y_j is minimal, neighbor function is zero. Define α_{ij} as neighbor function value, it is as follows:

$$\alpha_{ij} = I + K - 2\,. \tag{1}$$

In the clustering process, suppose y_i and y_j are in the same class, then we define that y_i and y_j are have connected each other, there are connection loss in every connection. In the algorithm, connection loss is defined as neighbor function value α_{ij} between the two sample. because $I,K \le N$-1, so neighbor function max value between y_i and y_j is:

$$\max \alpha_{ij} = N - 1 + N - 1 - 2 = 2N - 4\,. \tag{2}$$

Obviously $\alpha_{ij} > \max \alpha_{ij}, i \neq j$. the total loss in classes defined as:

$$L_{IA} = \sum_{i=1}^{N}\sum_{j=1}^{N}\alpha_{ij}\ . \tag{3}$$

Because y_i and y_j are in the same class, there is connection relation between y_i and y_j , so$\alpha_{ij} \neq 0$， if y_i and y_j are in different class, there is not connection, so $\alpha_{ij} = 0$.

The total loss between classes is as follow:

$$L_{IR} = \sum_{i=1}^{c}\beta_i\ . \tag{4}$$

Where c is constants, β_i is the loss of other class to class i. The cluster result should make loss between c classes is negative. We define :

$$J_{NN} = L_{IA} + L_{IR}. \tag{5}$$

Algorithm description. Because classification based fault sample is similar to the problem that ants look for food. Each fault sample data is a spot which one ant should visit. Each artificial ant accesses every sample data according to certain probability only once. The probability depends on the value of neighbor function of sample data and pheromone amount between sample data. The spot is added to the self data label of the ant, until each ant has visited all data sample. An ordered link of all sample data can be formed.

Then, in the label, by comparing the value of neighbor function of sample data, break down the connection between two samples that has the maximal value. Two initial fault classifications are formed, connection loss between each kind fault is computed, until the loss value is minimal. The fault classification is obtained at last. By comparing with each ant classification result, the running result that classification loss is minimal is chose as the current circle result. While the connection loss between classes of fault sample data is minimal, the algorithm running is over , the result is final solution.

Detailed algorithm. Step1: compute the weighted distance matrix Δ of fault symptom sample data, the element Δ_{ij} in the matrix is the weighted euclidean distance between the two samples y_i and y_j [4].

$$\Delta_{ij} = \left\| D(X_i - X_j) \right\|_2 = \sqrt{\sum^{m} P_k (x_{ik} - x_{jk})^2} \tag{6}$$

Where P_k is different weighted factor in fault symptom sample data.

Step2:making use of matrix Δ， neighbor matrix M of near fault sample is given. Its element is neighbor function value of sample y_i and y_j. In general, M is positive definite matrix, because the neighbor ordinal of sample are 1,2,…N-1, so the element in the matrix are integer.

Step 3: make neighbor function matrix L, matrix elements $L_{ij}=M_{ij}+M_{ji}-2$, if y_i and y_j have connection relation ,so their neighbor function value is given by L_{ij}. Let the diagonal elements L_{ij} is $2N$ or bigger.

Step 4: Each fault sample data is a spot which one ant should visit. According to neighbor function matrix of fault sample data, next sample data joins to its data label is decided by equation as follow:

$$p_{ij}^k(t) = \begin{vmatrix} \dfrac{\tau_{ij}^{\alpha}(t) L_{ij}^{\beta}}{\sum\limits_{k \in allowed} \tau_{ik}^{\alpha}(t) L_{ik}^{\beta}(t)} & if\ \ j \in allowed_k \\ 0 & otherwise \end{vmatrix} \tag{7}$$

Step5: the fault sample data that joined the ant data label are added in $tabu_k$(k=1,2,…m).

Step6: judge if all ants have visited all sample data one times, if not go to step 4.

Step7: according to the link status of fault sample data, comparing with neighbor function value of sample data, break down the connection between two samples with maximal neighbor function value, so the different fault classification is decided.

Step 8: compute all loss which are in the fault classifications and between the fault classifications by Eq (3) ~ (5), until $J_{NN}(k)$ of every ant is minimal, so once fault identification finished. Repeat step7~8, until $J_{NN}(k)$ of every ant is minimal.

Step9: the identification result that ants $J_{NN}(k)$ is minimal is chose as the current circle result.

Step 10: adjust pheromone of connection between fault symptom sample data.

$$\Delta\tau_{ij}^k = \begin{vmatrix} \dfrac{Q}{L_K} & if\ \ sample\ data\ i\ and\ \ j\ are\ linked\ by\ the\ ant\ k \\ 0 & otherwise \end{vmatrix} \tag{8}$$

Where L_k is the total loss of all connection.

Step11: judge circle times, while it get the max step times or J_{NN} is minimal, then stop running, compute is over ,the result is final solution. If not then go to step4.

Simulation examples

The algorithm is used to the process of fault identification and classification for fault diagnosis in hydraulic breakdown, a set of data of a hydraulic system is showed in Table 1. In the table, sample 1, 2, 3 are different level fault of hydraulic pump; sample 4, 5, 6 are different level fault of relief valve. Because no more space, data is given only partly in the table.

All simulation running parameter is given as follow : α=1， β=5， ρ=0.9， Q=100, minimal connection loss is 50, original pheromoneτ_0=10. In the example , ant number is fault sample quantity, m=6, we can get a team running result (X_1,X_2,X_3) and (X_4,X_5,X_6) with the algorithm.

The fifity times simulation results show that the classification of fault identification can be obtained by once cycle, fault identification is coincided with practical, the effectiveness and rapidity of the algorithm are fully illustrated.

Table1 Hydraulic System fault sample data

Fault type	sample	peak value	peak	Variance	Mean square amplitude
Hydraulic Pump fault	X_1	1.0315	0.6336	0.0122	0.1132
	X_2	2.8601	2.4979	0.0968	0.2675
	X_3	5.0551	4.6634	0.4127	0.5486
Relief Valve fault	X_4	0.7556	4.4358	0.0635	0.1028
	X_5	0.5579	3.3470	0.0597	0.0935
	X_6	0.6189	3.5426	0.0604	0.1107

Conclusion

The main characteristics of ant system are used enough in the algorithm: positive feedback process, distributed computation, greedy heuristic.In the algorithm, positive feedback process improves algorithm convergence speed; distributed computation begins to search at different start point, it can ensure correctness of fast convergence result; greedy heuristic is helpful to acquire acceptable identification result at early stage in algorithm running[5]. The algorithm is applied to breakdown diagnosis for hydraulic system, the results show that the algorithm has the advantages of high parallel, high effective of computing, rapid convergence, robust and credibility of the identification result.

References

[1] Hongliang Li , Guibao Song:Machinery Design ＆ Manufacture, Vol.25 (2011), p.139.In Chinese.

[2] Jie Pan, Xuesong Wang:Journal of China University of Mining ＆ Technology, Vol.41 (2012), p.108.In Chinese.

[3] M.Dorigo,in: *Ant Colony Optimization*, Tsinghua University Press, Beijing (2007).In Chinese.

[4] Jinggao Sun:Journal of East China University of Science and Technology,Vol.30(2004),p.194.In Chinese.

[5] Jie Chen:Mechanical ＆ Engineering Magazine, Vol.20(2003), p.67.In Chinese.