Improved Bacteria Foraging Optimization Algorithm for Solving Flexible Job-Shop Scheduling Problem

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Abstract: Bacterial foraging algorithm (BFO) is an emerging algorithm, which has been widely applied in many fields by researchers . This paper designed an improved adaptive step and stop condition for solving local-optimal and premature problems, and applied this improved algorithm to the flexible job-shop scheduling Problem(FJSP). According to the changes of crowding lever between bacteria, step's evaluation are divided into three stages. Numerical simulation shows that the improved algorithm has avoided local optimal and premature problems， and is superior to standard BFOA and genetic algorithm.

1 INTRODUCTION

Flexible job-shop Scheduling Problem (FJSP) is the extension of JSP. It is a typical NP - hard problem to optimize the allocation of production resources (Jingjing Cui, Yanming Sun, Lanxiu Che, 2011). In addition to take unprocessed process into account, allows a process to choose on multiple machines which have the ability to process. FJSP more complex than JSP in combinatorial optimization problem and more in line with the actual production environment, so it has important theoretical significance and practical value to study FJSP.

In recent years, there are a variety of intelligent optimization algorithm be used to solve FJSP at home and abroad, such as simulated annealing, ant colony optimization and genetic algorithm, Waligora G. propose the simulated annealing algorithm for solving multi-objective scheduling problem (Waligora G., 2014), achieved good effect. Qin Zhao studied queuing theory in the application of shop scheduling, and presents a detailed of theoretical basis(Qin Zhao, Fuqing Zhao, 2013). Hongjun Liu proposed a kind of new optimization genetic algorithm (Hongjun Liu, Shuai Zhao, 2011), blend the idea of annealing strategy and tabu search into genetic algorithm, combined with the simulated annealing mechanism and tabu search mutation mechanism, it is suitable for solving the workshop scheduling problem. Moslehi G. Proposed improved particle swarm optimization algorithm to solve multi-objective characteristic on flexible job shop scheduling problem (Moslehi G., Mahnam M., 2011). The algorithm through fitness function to judge the individual or group's location weather is the best, Bacteria foraging process can be described as three processes: tendency, replication and migration.

In this paper, based on original algorithm, through analyzing foraging behavior of individuals and populations, improved movement step and the iteration stop condition, effectively improve convergence rate and accuracy. Through compare with the original algorithm, the progressive of the algorithm be verified.

2 FLEXIBLE JOB SHOP SCHEDULING

Suppose processing workshop with W artifacts and M machines, each artifact contains one or more processes, each working procedure can be performed on one or more machine, the processing times on each machine can be predetermined. Express p_{ij} as the *ith* procedure of artifact W_i , $M^{P}{}_{ij}$ said optional machine set of process p_{ij} . FJSP problem can be simplified into two sub problems which are machine

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allocation and process order (Xiuli Wu, Zhiqiang Zhang and Yanhua Du, 2015): Machine allocation problem point that the process choose qualified processing machine basis on the optimization goal; Process scheduling problem refers to every process allocated on each machine in what order processing. In flexible manufacturing, there are many types of the optimization goal, Tasks, for example, the maximum completion time, the total load of the machine and the total processing cost, it is unlikely to achieve the optimal state of multiple targets at the same time, the utmost pursuit of most businesses is efficiency, namely, efficiently complete the general assignment in the shortest possible time. This paper set the maximum completion time as the optimization goal. The objectives function as follows:

$$min\, c_{max} = min(max(\, c_{ij}\,)) \tag{1}$$

c_{max} refers to the maximum completion time of scheduling task, c_{ij} refers to completion time of Process o_{ij} . In addition, during processing need meeting some assumptions, as follows:

$$\begin{aligned}&(c_{ij} - c_{hg} - p_{ijk})\, x_{hgk}\, x_{ijk}\, (\frac{y_{hgij}}{2})(\, y_{hgij} - 1) + \\ &(c_{hg} - c_{ij} - p_{hgk})\, x_{hgk}\, x_{ijk}\, (\frac{y_{hgij}}{2})(\, y_{hgij} + 1) \geq 0\end{aligned} \tag{2}$$

Formula 2 means there are two artifacts are not processing on the same machine. Among them, p_{ijk} refers to the processing time of process o_{ij} on machine k, x_{ijk} refers to the decision variable of the machine allocation, y_{hgij} refers to the decision variable of the order on process. Formula (4) qualified procedure can only be completed in one machine; (5), (6) limit the scope of the decision variables.

$$x_{ijk} = \begin{cases} 1, \text{if } o_{ij} \text{ is dune on machine } k \\ 0, \text{elsewhere} \end{cases} \tag{3}$$

$$y_{hgij} = \begin{cases} 1\ , & o_{hg} \text{ before } o_{ij} \text{ and adjacent} \\ -1, & o_{hg} \text{ behind } o_{ij} \text{ and adjacent} \\ 0\ , & \text{otherwhere} \end{cases} \tag{4}$$

$$\sum x_{ijk} = 1, k \in s_{ij}, \forall i, j \tag{5}$$

$$x_{ijk} \in \{0,1\} \tag{6}$$

$$y_{hgij} \in \{-1,0,1\} \tag{7}$$

3 IMPROVED BACTERIAL FORAGING ALGORITHM

3.1 Bacterial Foraging Optimization Algorithm

BFOA abstracts from the biological foraging behavior of bacterial. The foraging process was described as three operation process, including tendency, replication and migration. The optimal performance is largely decided by numerous parameters, such as bacteria population size, bacteria movement step, tendency operations, the maximum times of copy and transfer operation. Due to these parameters have no adaptability, Its iterative times is completely determined by the maximum times of various operation, and no convergence criterion are introduced, so it is difficult to ensure accuracy and adding unnecessary iterative process. In this paper, The improvement point on two aspect, there are bacteria movement step and stop condition (Dalian Yang, Xuejun Li and Lingli Jiang, 2012).

1) Tendency operations: Mainly simulate the motor processes, including move forward and move towards. Assuming that flora size is S, With D vector $p_i = (\, p_1^i, p_2^i, \ldots, p_n^i)$ represent the *ith* a bacteria, $p^i(j,k,l)$ said the chemotactic operations of bacteria *i in* the *jth*. The position after the kth times copy operation and the *ith* times migration operation means that a candidate solution of bacteria *i* in the search space. The location updating formula of the bacteria *i* after chemotactic operations as follows:

$$p^i(j+1,k,l) = p^i(j,k,l) + c(i)\varphi(j) \tag{8}$$

Among them: $c(i)$ represent chemotaxis step length of bacterial i ; $\varphi(j)$ represent a random direction vector after bacteria i overturn, $\varphi(j) = \theta(i)/[\theta(i)^T\theta(i)]^{1/2}$.

2) Replication operations: Bacteria will be divided after completed the sated tropism times, this operation is mainly simulates the breeding process of bacteria individual evolution. Assumes that the size of bacterial population is N, $F^i(j,k,l)$ as the *ith* individual fitness value, first, for the fitness of the whole population in descending order, The first $N/2$ individuals will be survived which order by

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fitness value, And make no difference to split in two, the lower $N/2$ individuals are eliminated, when completed such a copy operation, the bacteria population will remain the same size.

3) Migratory operation: In order to improve the global search ability of the algorithm, When a problem's solution space have multiple extremum points, its sociality make it easy to trap in local extremum, the purpose of this process is to make the new individual to replace the original individual, Different from the copy operation, the occurrence of migration is according to certain probability p, When some bacteria can meet the conditions of the migration, it will be randomly assigned to the solution space.

3.2 Improved Bacteria Movement Step

Traditional algorithm using fixed chemotactic step length, but BFOA is a dynamic process. The bacteria activity will have a certain percentage of the decline with each tendency operation. The greater step size is, the more likely miss the optimal solution, it will soon fall into local optimum. With the increase of number of chemotactic, step length should make appropriate adjustments, to maintain the searching efficiency of the algorithm.

Through studying found that step length affected by the number of nearby companions, namely crowding level of population, the more crowded the higher demand for food, food consumption faster, just search for this position, the individual fitness may increase, but as more and more individual learning to this position, the individual fitness declines quickly, which requires quick to flee the area, sat with adaptive step length to control the residence time of an area, continue to look for a better position. For above, this paper presents an improved bacteria movement step for this problem. congestion level of the region which Bacteria i in, determined by the individual number and interval length in this region, $crowd = n/len$; Δt_j said the difference of the fitness value between $cs(i)_{(j,k,l)}$ and $cs(i)_{(j-1,k,l)}$, represent the fitness value of the bacteria i after the ith tendency operation, the kth copy operation, the lth replication operations.

$$\Delta t_j = cs(i)_{(j-1,k,l)} - cs(i)_{(j,k,l)} \tag{9}$$

Step length have three changes, the early stage of the search in global optimization , Few bacteria around, that within a certain range inadequate nutrition, sets the chemotactic compensation to a larger value, be helpful for global optimization, when looking for the crowded degree of large scope, into local optimization, set small step length, so as not to miss the optimum solution, when the congestion is too large and the growth rate of individual fitness gradually smaller, step length will gradually increase, so as not to fall into local optimization.

$$S(i) = \begin{cases} S_{max}, & crowd > \partial \\ S_{min}, & crowd < \partial \\ S_{max} - \dfrac{(N_i - 1)}{N - 1}(S_{max} - S_{min}), & crowd > \partial \text{且} \Delta t_{j-1} < \Delta t_j \end{cases} \tag{10}$$

Among them, N_i represent the tendency times have been executed in current, N represent total times, S_{max} represent the maximum step length, S_{min} represent minimum step length. ∂ is the preset threshold.

3.3 Improved Termination Condition

Appropriate termination condition can ensure to obtain optimization results with reasonable accuracy, and, reduce unnecessary computation. BFOA is actually a process with constant iterations and convergence, its goal is to improve convergence speed and computational precision (J Q Li, Q K Pan and K Z Gao, 2012). In practical applications, it is unknown about the optimal solution. we can't determine whether to stop the iteration by judging the magnitude of the error between current solution and real solution, through above mentioned analyzing, Population movement step can is the basis of iterative stop. The step size smaller, the bunching of bacteria more concentrated. The iteration will stop until the following expression was founded (ε is a smaller number) :

$$[\max((F(j,k,l)) - \min((F(j,k,l))]M_2 < \varepsilon \tag{11}$$

3.4 Algorithm Implementation Steps

The execution steps of the IBFO to solve the optimal value as follows:

Step 1: Initialize parameter.

Step 2: Initialize bacteria position. Generate initial solution randomly in the feasible region, The according to formula (2) and (3) calculate individual adaptive value. Always keep the ethnicity in a reasonable range.

Step 3: Perform tendency operation. According to the formula (3), (4), (5) adaptively adjust tendency step. When the adaptive value rise, keep moving direction. When adaptive value falls, rotate to select

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new direction. If reach to the upper limit of tendency operation, then step out the tendency, and perform step 5.

Step 4: Perform replication operation.

Step 5: Perform tendency operation.

Step 6: Whether algorithm meet the convergence conditions. If convergence, output the run results and terminates the running process; otherwise, return to step 3.

4 APPLICATION OF EXPERIMENT

4.1 Experimental Environment

All experiments were paper processor for Intel (R) Core (TM) i5-34700 CPU @ 3.20GHz, 4.00GB RAM, Windows 7 systems under the.

4.2 Computational Results

To BFO algorithm, The most important impact of the efficiency is the times of tendency, the more times, the optimization ability in local is more subtle. At the same time, with increasing complexity, followed by the size of the bacteria, the more bacteria involved in foraging individuals, the faster to find the optimal solution, but the computational cost will increase; Again is the influence of migration dispel, this factor determines the global search ability of the algorithm, it is easy to fall into local optimization if the times is too small, therefore, too many will increase the complexity of the algorithm(Shiv P, Deo PV., 2014).Through integrated balance, through many experiments to obtain the optimal experimental parameters: Flora scale S = 100, Maximum Iterations N_{iter}= 200,tendency times $N_c=50$, maximum swimming times $N_s= 10$,copy times N_{re}= 10, migration times N_{ed}= 15.

Choose two instances make simulation experiment: The 8 x 8 is part of the flexible scheduling problem (P-FJSP), 10 x 10 is fully flexible scheduling problem (T-FJSP)(Bagheri A., Zandieh M. and Mahdavi I.,2010).Compared IBFO algorithm with standard BFO algorithm and the improved genetic algorithm (IGA). Three algorithms run 10 times respectively, the running results are shown in table 2 and table 3.

Table 1 8 × 8 results by comparison

Algorithm	Optimal	Average	standard deviation
BFO	17	19.0	2.31
IGA	13	16.1	1.23
IBFO	13	14.8	0.80

Table 2 10 ×10 results by comparison

Algorithm	Optimal	Average	standard deviation
BFO	9	11.2	1.88
IGA	8	7.9	1.02
IBFO	8	7.4	0.71

Moreover, The experiment choose MK01 experiment(Brandimarte Paolo, 1993) to verified which involved in Benchmark examples, 6 machine, 10 artifacts. In the number of 200 iterations the experimental analysis was carried out on the three algorithms respectively. Figure 1 is the convergence curves about the three algorithm, can be seen from the diagram, In this paper, optimization algorithm and the IGA algorithm can search to the optimal solution 38, standard BFOA algorithm search to a solution 41, although the two algorithms can get the optimal solution, but the convergence speed of IGA algorithm significantly slower than the improved algorithm. Improved algorithm would find optimal solution after 30 times in the iteration, and, IGA find the optimal solution after 70 iterative times, so the algorithm can more quickly find the optimal solution. Figure 2 is the Gantt diagram of improved BFOA; represent the scheduling scheme in the process of convergence. The Y-axis means machine number. The X-axis means execution time.

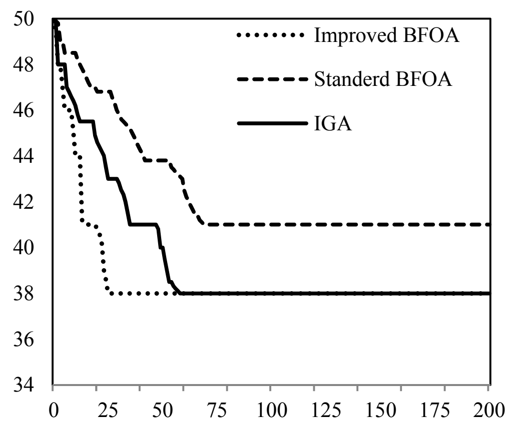

Figure 1 Convergence curves

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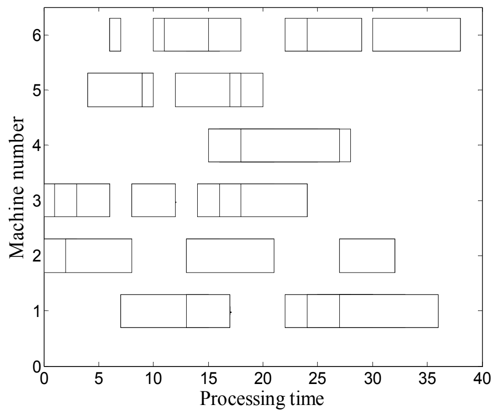

Figure 2 Optimal scheduling of Mk01 (The shortest completion time is 38））

5 CONCLUSION

An improved bacterial foraging algorithm is proposed in this paper, and applied to search for the optimal solution on FJSP. Compared with the traditional algorithm, the optimization ability of this method is more accurate. Compared with the improved genetic algorithm, the improved method can reduce the iterative time and greatly reduce the solving time. But in view of the BFOA program is running slightly slow, and have numerous parameters, the present study mainly focus on the single objective optimization, need to strengthen the research for solving combinatorial optimization problem.

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