A Job Shop Scheduling Method Based on Ant Colony Algorithm

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***Abstract*—The problem of job shop scheduling is a hot research topic nowadays. How to improve the production efficiency of the equipment and shorten the processing time of the workpieces has become an important research work. The parallelism and mechanism of distributed computing of Ant colony optimization (ACO) provide a good solution in solving job shop scheduling problems. In this paper, the ACO is applied to the job shop scheduling of industrial production. And the ACO is used to solve the scheduling problem, the pheromone update strategy in the ant colony algorithm has been modified, and roulettes wheel was introduced. On the basis of above modifications, a job shop scheduling method based on ant colony algorithm has been used in this paper. In addition, the disjunction graph model of the job shop problem has been also established in this paper, which turned the job shop scheduling problem into a solution to the traveling salesman problem and then redefined as a natural expression model suitable for ant colony algorithm. When solving the traveling salesman problem, virtual nodes were added as the super source and destination in the search process, the distance between cities and the shortest path in the traveling salesman were corresponded with the processing time and the shortest processing time in the job shop scheduling problem one by one. In this paper, C++ has been used for programming, and the FT06 data example was used as a test example. In the experiment, the scheme of job scheduling with minimum total completion time was obtained successfully, which verified the feasibility and effectiveness of this method in the shop scheduling problem.**

Keywords—Job-Shop problem, Ant Colony Algorithm, Intelligent optimization

I. RESEARCH BACKGROUND AND PROBLEM DESCRIPTION

A. Research Background

Job shop scheduling problem (JSP) is proved to be a typical NP hard problem by experiments. The solution space of the problem becomes more and more complex with the increase of data, but the job shop scheduling problem is essentially a kind of resource allocation problem that meets the requirements of sequence and processing constraints. After continuous research, Johnson published an article on the research method of two machine flow scheduling problem[1], which lays a foundation for the research of job shop scheduling problem. Subsequently, Rodammer F.A. and Jackek B. summarized in detail the hybridity of relevant models and problems of scheduling methods, and divided the methods for solving production workshop scheduling problems into two types: accurate algorithm and approximate algorithm[2]. Based on multi-objective\dynamic uncertainty and computational complexity of the scheduling problem [3],a scheduling method based on ant colony algorithm has been used in this paper. If the job shop scheduling problem has only one solution, the pheromone will cause fuzzy errors, and the use of ant colony algorithm will increase the time complexity of the problem. With the increasing complexity of job shop scheduling problem, ant colony algorithm will have higher efficiency, which will be proved in detail in this paper. In order to improve the convergence accuracy and convergence speed and obtain the shortest path of the traveling salesman problem faster, the traditional ant colony algorithm is slightly modified, and the heuristic idea is used to gradually approach the optimal solution, so as to transform it into the shortest processing time of the workshop scheduling problem and obtain a satisfactory suboptimal solution.

B. Problem Description

JSP problem as a hot issue is easy to express and difficult to solve. It can be roughly described as: for a given set of workshop equipment and workshop workpieces, multiple processes are required to complete, and there are sequential constraints between the processes. The job shop scheduling problem needs to consider certain constraints, which can be described as follows [4]:

1) If the processing work starts, it cannot be interrupted.

2) The processing time and sequence constraints required for each operation to be processed have been determined, and they are not affected by the change of processing sequence.

3) At the same time, one equipment can only process one job, and there is no possibility of processing multiple jobs at the same time.

4) At the beginning of processing, each workpiece may be selected for processing.

5) There is no sequence requirement for the processes to be processed of different workpieces, but there is a certain sequence with the level sequence constraint relationship between the processes of the same workpieces to be processed.

6) Other auxiliary time is not considered.

Ant colony algorithm has a series of advantages, such as good parallelism, stronger robustness and so on. Therefore, it can quickly and effectively optimize the machine processing process by improving the job shop scheduling problem through ant colony algorithm.

The problem to be solved in scheduling is to complete the processes of all workpieces in the agreed order and finally complete the processing of all workpieces. Job shop scheduling which contains many categories is chaotic and complex. It is found that the categories of job shop scheduling can be roughly summarized into the following types: Job shop scheduling and flexible Job shop scheduling, open-loop and closed-loop workshop, uncertain and deterministic scheduling, sequential and non sequential scheduling [5]. In this paper, the shortest processing time is set as the research goal, and the objective function is set to seek the minimum processing time without considering other factors such as flexibility, so as to minimize the maximum processing time. The deterministic scheduling problem has been solved in this paper, that is, to get the shortest processing time, and the disturbance in the production process is small. The parameters such as processing time are determined. In the given problem, these quantities are determined values.

II. Correlation Theory

A. Travelling Salesman Problem

Traveling salesman problem (TSP) as a combinatorial optimization problem essentially has been applied widely. With the increase of experimental data, the complexity of TSP problem will increase rapidly, so it belongs to a typical NP hard problem. Traveling salesman problem (TSP) is easy to describe, but it is difficult to solve. In the current study and research, swarm intelligence algorithms such as ant colony algorithm have unique advantages in solving TSP problems, and have achieved good results in practical application, which improves the efficiency of solving TSP problems and expands the scope of application. If the TSP problem is transformed into a graph theory model [6],that is ,each node in the graph represents a specific city, the edge between vertices represents the path between two adjacent cities, and the travel distance or cost between two cities is represented by the weight of the edge on the two nodes. Based on the above basis, the traveling salesman problem will be abstracted to find the shortest Hamiltonian loop in a graph in order to realize the transformation of the problem model.

B. Ant Colony Optimization

Ant colony optimization (ACO) is a bionic swarm intelligence algorithm. In fact, ant colony algorithm is a combination of meta heuristic search and positive feedback principle. The idea of ant colony algorithm comes from the process of ant foraging[7]. The foraging activities of ant colony are very obvious intelligent behavior. Ant individuals can cooperate with each other to find the best path between the required food location and ant nest, and finally successfully find a more satisfactory suboptimal solution or optimal solution. In order to better understand the ant foraging process, as shown in Fig. 1 [8]:

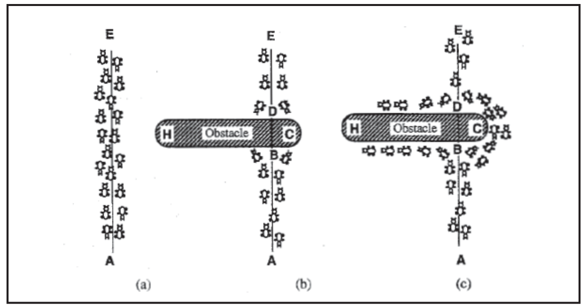

Fig.1. Ants foraging in nature

As shown in Fig. 1 (a), without any obstacles, ants will forage along the straight path between the ant nest and food. In Fig. 1 (b), when there is no obstacle, the ant needs to bypass the obstacle. When passing point B, the ant needs to make a decision. Finally, as shown in Fig. 1 (c), most ants choose a shorter path as the search path.

Ant colony algorithm has many advantages, such as excellent distributed computing power and robustness, global optimization and essentially parallelism. Ant colony algorithm is a random heuristic optimization algorithm, which broadens the solution to NP hard problems such as job shop scheduling [9].

III. Job Shop Scheduling Method Based On Ant Colony Algorithm

A. Establishment of Problem Model

With multi constraints and complexity, if ant colony algorithm is used to solve the problem to solve related problems, the key is to transform the JSP problem into a natural expression model which is suitable for ant colony algorithm [10]. We can regard the process of each workpiece as the corresponding city in the TSP problem, then convert the processing time of each process into the travel cost or distance between cities in the TSP problem, and regard the process completion time as the travel cost or distance of all cities in the TSP problem. We can realize the transformation from the job shop scheduling problem to the traveling salesman problem, in order to make it more suitable to use ant colony algorithm. In the scheduling process, the objective function is set to minimize the maximum processing time, that is, the processing time of all processes of this batch of workpieces is the minimum. Assuming the system in this paper has m processing machines that can be used, n jobs that need to be processed, and each job contains at least two processes, the mathematical model of job shop scheduling can be expressed as:

The scheduling goal of the scheduling model in this paper is to complete the machine that is completed at the latest as soon as possible:

$$F= min(max(C_k)), k = 1,2, \dots m \quad (1)$$

The constraints are as follows:

1) Sequential, that is, an operation can only process the next operation after processing the previous operation:

$$S_{ij} - S_{i(j+1)} + T_{ij} \leq 0, i = 1,2,3\dots n; j = 1,2, \dots , E_i - 1 \quad (2)$$

2) Timeliness: the starting time of the first operation of a substitute workpiece is greater than or equal to 0:

$$S_{i1} \geq 0, i = 1,2,\dots,n \quad (3)$$

3) Uniqueness: the process of a workpiece to be processed can only be processed by one equipment in the workshop, and other processes of the workpiece cannot be processed:

$$Y_{\mathrm{ijk}} = Y_{pqk} = 1 \& S_{ij} - S_{pq} + T_{ij} \leq 0 \parallel S_{pq} - S_{ij} + T_{pq} \leq 0, i \neq p \quad (4)$$

Where C_k represents the time of the k-th equipment completes processing, S_{ij} represents the start processing time of the j-th process of workpiece i to be processed, E_i represents the number of processes contained in workpiece i, T_{ij} represents the time required for processing of the j-th process of workpiece i to be processed, Y is a boolean variable, Y_{ijk} represents whether the j-th process of workpiece i is processed on machine k, If yes, set Y to true, otherwise set to false. The JSP workshop scheduling problem can be represented by disjunctive graph [11], which is shown in 3 below × 3 JSP workshop scheduling problem as an example, node 0 and node 10 in Fig. 2 are virtual nodes, which are set to realize the transformation from workshop scheduling problem to traveling salesman problem. They represent the start node and end node respectively. The solid line in Fig. 2 represents the joining arc, connecting different processes of a workpiece to be processed, and they have certain sequence constraints. The direction of the arrow in the figure indicates the sequence of process completion, that is, the constraint relationship of processes in the same workpiece. The dotted line with double arrows represents the disjunctive arc, which connects the processes processed on the same equipment (not belonging to the same workpiece).

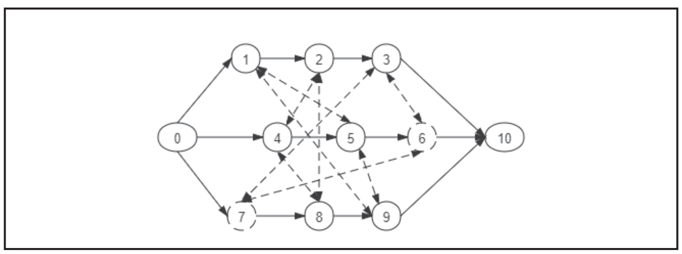

Fig.2. 3×3Disjunctive graph

B. Parameter Setting

In ant colony algorithm, the setting of each parameter value has an important impact on the solution efficiency of ant colony algorithm. The rules to be set in this model include state transition rules, pheromone initial value setting and update rules, as well as algorithm termination conditions.

In this scheduling scheme, the number of ants at the initial time is m, and the pheromone τ_0 at the initial time is equal. In this paper, it is set that the ant selects the next node by using roulettes wheel. The selection probability of ant K (k = 1,2,..., m) is:

$$p_{ij}^{k} = \begin{cases} \frac{[\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}(t)]^{\beta}}{\sum_{k \in allowed_k} [\tau_{ik}(t)]^{\alpha} \cdot [\eta_{ik}]^{\beta}}, j \in allowed_k \\ 0, \quad \text{others} \end{cases} \quad (5)$$

In the formula(5), τ_{ij} is the pheromone content from node i to node j, η_{ij} is the heuristic information between nodes, which reflects the degree of pheromone influence on ants during state transition. The mathematical formulas is usually expressed as:

$$\eta_{ij} = \frac{1}{d_{ij}} \quad (6)$$

d_{ij} is the processing time of process and $d_{ij} = T_{ij}$ is the processing time of process J. allowed_k represents the set of nodes that ant K can access in the next step. α is the pheromone heuristic factor, which reflects the strength of the role of random factors in the search path process of ants. The greater the value of α, the greater the influence of pheromone content on ant path selection. if $\alpha = 0$, the pheromone level is not considered, and the algorithm becomes a random greedy algorithm with multiple starting points; β is the expected value heuristic factor, which reflects the influence of heuristic information. The greater the value of β, the easier it is to select the node closer to the ant, and β=0 algorithm is transformed into a typical positive feedback heuristic search.

After calculating the selection probability of each path, the roulette for path selection has been selected in this paper. A roulette is divided into several different parts with different sizes. Each part represents the selection probability of ants choosing a path.

Pheromone update rules include local update strategy and global update strategy. At the initial time, the pheromone on the path is set to τ_{max}, and ρ takes a smaller value, so that the algorithm has better ability to find excellent solution space. It has been stipulated that the pheromone concentration is limited to the range interval $[\tau_{min}, \tau_{max}]$, where τ_{min}, τ_{max} are the upper and lower bounds of pheromone respectively. If the pheromone concentration of a path exceeds the limited interval, it will be updated to τ_{max}, which makes it possible for the next ant to be selected even if the path has not been selected [12].This update mechanism can prevent the pheromone content of one path from far exceeding that of other paths, so as to avoid stagnation and falling into local optimal solution. We define the pheromone update formula at time t + 1 as follows [13]:

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \Delta\tau_{ij}(t) \quad (7)$$

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{m} \Delta\tau_{ij}^{k}(t) \quad (8)$$

Where ρ represents the Volatilization Coefficient of pheromone on the path, $1-\rho$represents the pheromone residue factor on the path, usually $0 < \rho \leq 1$. $\Delta\tau_{ij}^{k}$ represents the pheromone released by the kth ant on its path, which can generally be defined as:

$$\Delta\tau_{ij}^{k} = \begin{cases} \frac{1}{d_{ij}}, & if \text{ (i,j) } on\ path \\ 0, & others \end{cases} \quad (9)$$

The termination condition of the algorithm is to reach the set maximum number of iterations or the optimal solution does not further optimize or change with continuous iterations. In this paper, the maximum number of iterations is selected as the termination condition.

C. Algorithm Description

Job shop scheduling method based on ant colony algorithm has been researched in this paper.At the initial time, the ants are placed at the super source point (virtual point), the parameters and pheromones on the path are initialized, and all ants are set to move towards the end point (virtual point). The problem is transformed into a traveling salesman problem for solution. After many iterations, excellent solutions will be gradually obtained, then an excellent workshop scheduling schemem will be generated. The following figure is the flow chart of workshop scheduling method based on ant colony algorithm.

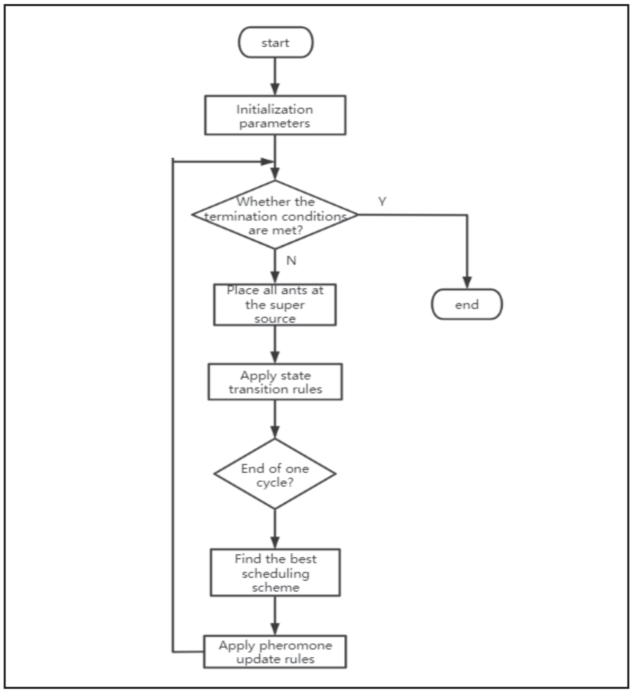

Fig.3. Ant algorithm flow chart

Step 1: Initialize the parameters in the system, set the number of ants to m, the pheromone concentration on the initial path to τ_0, the pheromone increment to 0, and finally initialize the number of cycles to 0.

Step 2: According to the number of initialized ants, put all ants into the super source point which has been introduced, and initialize the feasible node set;

Step 3: Set the number of ants k=k+1(initial time k = 1);

Step 4: Apply the state transition rule and calculate (t) the probability of transfer between the optional node and the current ant node in the current scheduling time according to (5). Calculate the heuristic information intensity according to formula (6) and the pheromone concentration between nodes according to formula (7), and then calculate the selection probability of each path, so as to provide reference for ant path selection.

Step 5: Determine the processing time and processing completion time of each operation according to the required running time of the operation in the problem. After selecting each node, the ant must modify the visited list once, that is, add the visited node to the ant's visited list to ensure that each ant has visited all nodes, otherwise return to step 4.

Step 6: If M ants in the ant colony have not visited all nodes, jump to step 3, otherwise it indicates that the current iteration is over and start the subsequent work.

Step 7: After a cycle (i.e. iteration) is completed, calculate the objective function value of the search result according to the objective formula(1), and recalculate the pheromone concentration on all paths.

Step 8: If the upper bound of the number of cycles of the ant colony algorithm is not reached, turn to step 2, otherwise directly select the current shortest path, that is, the optimal solution, as the final selection result.

IV. Experimental Results and Analysis

A. Experimental Result

The example of MT06 (FT06) with the scale of in the famous job shop benchmark problem as the data set for verification was used in the paper. It is confirmed by Fisher and Thompson that the optimal solution (shortest processing time) of the problem is 55.

TABLE 1. FT06 or MT06 Job-Shop Data

Machine constraint matrix	**Processing time matrix**
3 1 2 4 6 5；	3 10 9 5 3 10；
2 3 5 6 1 4；	6 8 1 5 3 3；
3 4 6 1 2 5；	1 5 5 5 9 1；
2 1 3 4 5 6；	7 4 4 3 1 3；
3 2 5 6 1 4；	6 10 7 8 5 4；
2 4 6 1 5 3；	3 10 8 9 4 9；

In this paper, the above examples are verified, and the scheduling scheme with the minimum total completion time is obtained, which met the above machine constraints. The initial pheromone concentration τ_0 of the road is set to 3000, the volatilization coefficient ρ is set to 0.5, the maximum number of iterations is carried out for 10 times, the pheromone concentration of ant colony on the path is limited to 1000-3000, and the number of ants m is twice the number of processes, that is, 72. After many experiments, this method successfully finds the shortest processing time, which shows that this method can be effectively applied to the actual production workshop scheduling. Fig.4 is the Gantt chart of this processing scheme. From the chart, we can get the specific time for different machines to process different kinds of workpieces, as shown in Table 2.

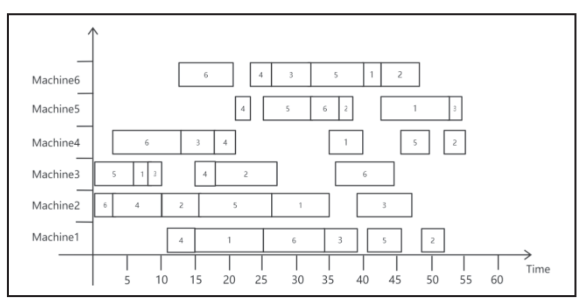

Fig.4. Workshop scheduling Gantt chart

TABLE 2. WORKING HOURS OF DIFFERENT MACHINES

Machine number	The order of(Workpiece number,Operation No,Processing time)
1	(4,2,4) (1,2,10) (6,4,9) (3,4,5) (5,5,5) (2,5,3)
2	(6,1,3) (4,1,7) (2,1,6) (5,2,10) (1,3,9) (3,5,9)
3	(5,1,6) (1,1,3) (3,1,1) (4,3,4) (2,2,8) (6,6,9)
4	(6,2,10) (3,2,5) (4,4,3) (1,4,5) (5,6,4) (2,6,3)
5	(4,5,1) (5,3,7) (6,5,4) (2,3,1) (1,6,10) (3,6,1)
6	(6,3,8) (4,6,3) (3,3,5) (5,4,8) (1,5,3) (2,4,5)

B. Experimental Analysis

Because ant colony algorithm has some shortcomings, such as slow convergence speed and poor stability. In the initial stage, the pheromone content in the paths are the same, which has little effect on ant path selection. When the problem data gradually expands, it is difficult to find a better scheduling scheme in a short time because of the slow convergence speed. With the continuous search of ants and the increasing number of iterations, the positive feedback mechanism in ant colony algorithm will work. As can be seen from Fig. 5, when the number of iterations is small, there is a certain gap between the found optimal solution and the real optimal solution. After a certain number of iterations, the optimal scheduling scheme can always be found after multiple runs, which also shows that this method can be effectively applied to the scheduling problem of production workshop.

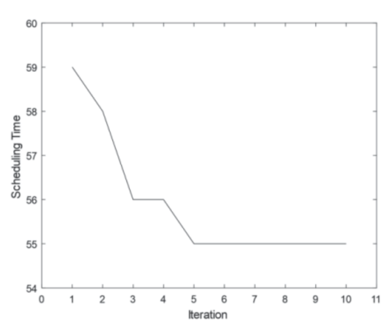

Fig.5. optimal solution evolution curve

V. SUMMARY AND PROSPECT

In recent years, job shop scheduling problem has been concerned by scholars at home and abroad. It is widely applied with strong practical value. Bionic swarm intelligence algorithms such as genetic algorithm and ant colony algorithm are often used to solve optimization problems. In this paper, ant colony algorithm is applied to the job shop scheduling problem, and the experimental verification is completed by C++ programming. The experimental results have shown that this method can effectively solve the job shop scheduling problem. Because ant colony algorithm has the advantages of implicit parallelism, robustness and easy integration with other intelligent methods [14], it is widely used in combinatorial optimization and job shop scheduling problems. The use of ant colony algorithm can effectively overcome the problems of low equipment utilization and long scheduling cycle in the actual production workshop. However, ant colony algorithm still has some shortcomings, such as slow convergence, easy stagnation or limited to local solutions, which need to be solved in the future. How to further improve the convergence speed of ant colony algorithm, strengthen the mutual integration between algorithms and improve the efficiency of solving problems will become a new development trend.

At present, the research on job shop scheduling problem is not only limited to the pursuit of efficiency, but also the pursuit of flexibility of job shop scheduling. Flexible job shop scheduling problem (FJSP) is a general example of job shop scheduling problem. It can further improve the production efficiency of the production workshop. We will focus on the flexibility of job shop scheduling while pursuing efficiency in the future research.

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