Research on Job-shop Scheduling Problem Based on Bee Colony Algorithm

Xiaojun Long, Jingtao Zhang, Shuai Yang, Wanying Wu, Yongbo Sun, Zhanhe Guo and Kai Zhou*

School of Mechanical and Electronic Engineering, Shandong Agricultural University, Tai’an, China

*Corresponding author e-mail: zhoukai2017@sdau.edu.cn

Abstract. The job-shop scheduling problem (JSP) is currently a problem that affects processing efficiency and economic benefits in large-scale processing workshops. JSP aims at the optimal completion time, which is a difficult process arrangement and machine allocation problem. Artificial bee colony (ABC) algorithm is a common algorithm to solve JSP. Firstly, this article introduces the problem of job-shop scheduling, secondly analyzes the principle of the ABC algorithm, and finally verifies the effectiveness of the ABC algorithm in solving JSP through experiments.

Keyword: Job-shop Scheduling Problem (JSP); Artificial bee colony (ABC).

1. Introduction
Job-shop scheduling is a difficult combinatorial optimization problem, which is one of the key problems in the current machining workshop especially in large-scale machining workshop. Since JSP was proposed, many scholars at home and abroad have conducted research on it for decades, and many intelligent algorithms have been applied to solve JSP. Jiang [1] applied the gray wolf optimization (GWO) algorithm to JSP, introduced crossover and mutation operators, and balanced the GWO's global exploration and local development capabilities; Huang et al. [2] designed state transition rules and pheromone update strategies based on the ant colony optimization (ACO) algorithm, and verified the stability of ACO in solving JSP; Liu et al. [3] improved the particle swarm optimization (PSO) algorithm so that its coefficients can be dynamically adjusted with the fitness value, which improves the efficiency of the PSO algorithm; Chen et al. [4] combined GA algorithm with SARSA and other reinforcement learning (RL) algorithms, and proposed a self-learning genetic algorithm based on RL, which effectively solved the JSP problem through mutation and genetic operations.

As a common algorithm for studying JSP, ABC algorithm has received widespread attention at home and abroad. This paper analyzes the JSP and ABC algorithms, and verifies the effectiveness of ABC through MATLAB experiments.

2. Job-shop Scheduling Problem
Assuming that X workpieces need to be processed in a processing workshop at the same time, and each workpiece has Y processes, how to arrange these many processes on Z machines in the workshop reasonably, so that the final completion time is the shortest, this is the so-called JSP. In the process of
researching job-shop scheduling, it should be noted that the processes of each workpiece must be processed in order, and there is no processing sequence relationship between different workpieces. Equation 1 is the function of the minimum completion time in JSP.

\[ T_{\text{min}} = \min (\text{max} t_z) \]  

(1)

In Equation 1, \( T_{\text{min}} \) represents the minimum completion time, and \( \text{max} t_z \) represents the time consumed by the machine with the longest processing time.

3. Artificial bee colony algorithm

The ABC algorithm is an intelligent optimization algorithm proposed by Karaboga [7]. Since its inception, it has been studied by a large number of scholars. The ABC algorithm includes three types of bees: employed/hired bee, onlooker bee, and scout bee. First, the hired bees conduct an improved search for the current honey source, generate new honey sources, and greedily choose better honey sources; Secondly, the onlooker bee selects a honey based on the information shared by the hired bee, performs a neighborhood search, and greedily selects a better honey source; Finally, the hired bees gave up the honey source and turned into the scout bees, and randomly searched for new honey sources [8-9]. The main steps of ABC are as follows:

(1) Population initialization;

Set the number of honey sources to “n”, and the equation for generating honey sources is shown in Equation (2).

\[ S_{m_i} = L_i + (U_i - L_i) \times r_1 \]  

(2)

In the above equation, \( S_{m_i} \) represents the i-th honey source, \( r_1 \) represents a random number in (0,1), and \( U_i \) and \( L_i \) represent the upper and lower bounds of the j-th dimensional variable, respectively.

(2) Hired bee stage;

Each hired bee will generate a new honey source near the corresponding honey source, as shown in Equation (3).

\[ S_{i_j} = S_{m_i} + (S_{m_i} - S_{k_j}) \times r_2 \]  

(3)

In the above equation, \( r_2 \) is a real number in [-1,1]. If the fitness value of the new honey source \( S_{i_j} \) is better than the fitness value of the original honey source \( S_{m_i} \), the new honey source replaces the original honey source, otherwise the original honey is retained.

(3) Onlooker bee stage;

The honey source is selected by the probability \( P \), and the calculation equation is shown in Equation (4).

\[ P = \frac{f_i}{\sum_{i=1}^{n} f_i} \]  

(4)

In the above equation, \( f_i \) represents the fitness of \( S_i \), the larger the \( f_i \), the greater the probability of \( S_i \) being selected.

(4) Scout bee stage;

If the honey source \( S_i \) does not improve after multiple iterations, the scout bee generates a new honey source through Equation (2).

4. Experimental verification

To prove the effectiveness of the ABC algorithm in solving JSP, this article does an experiment on it. In this paper, MK1 example in Brandimarte example [10] is used as the experimental object. There are 6 machines and 10 workpieces in total, and each workpiece has 5 to 6 processes. The population number in the ABC algorithm is set to 300, and the number of cycles is 2000, which is verified by MATLAB. Figure 1 shows the change trend of the optimal completion time. It can be seen that the optimal completion time has reached a stable value of 42 after 2000 cycles.
**Figure 1.** Trend of optimal completion time.

Figure 2 is the scheduling diagram of the job-shop scheduling task. In figure 2, "4-2" means that the second process of the workpiece 4 is processed on the machine 2, and the processing time of each process is arranged.

**Figure 2.** Job-shop scheduling task planning diagram.

Table 1 is the machine corresponding to each process in Figure 2, which is the best scheduling plan for MK1.

**Table 1.** The optimal scheduling plan for Job-shop tasks.

| Workpiece | Y₁ | Y₂ | Y₃ | Y₄ | Y₅ | Y₆ |
|-----------|----|----|----|----|----|----|
| X₁        | Z₁ | Z₃ | Z₆ | Z₁ | Z₃ | Z₆ |
| X₂        | Z₂ | Z₁ | Z₁ | Z₆ | Z₄ | Z₆ |
| X₃        | Z₃ | Z₆ | Z₁ | Z₃ | Z₃ | Z₁ |
| X₄        | Z₁ | Z₂ | Z₃ | Z₃ | Z₅ | Z₆ |
| X₅        | Z₃ | Z₆ | Z₂ | Z₁ | Z₄ | Z₃ |
| X₆        | Z₆ | Z₁ | Z₃ | Z₂ | Z₆ | Z₃ |
| X₇        | Z₆ | Z₁ | Z₃ | Z₃ | Z₅ | Z₁ |
| X₈        | Z₆ | Z₁ | Z₃ | Z₆ | Z₂ | Z₂ |
| X₉        | Z₆ | Z₃ | Z₄ | Z₁ | Z₃ | Z₄ |
| X₁₀       | Z₆ | Z₃ | Z₅ | Z₆ | Z₄ | Z₁ |
5. Conclusion
First, this article introduces JSP and describes the constraints of JSP; Secondly, the ABC algorithm is introduced, and its operation principle is analyzed; Finally, an experiment was carried out through MATLAB, and the optimal scheduling plan was obtained, which verified that the ABC algorithm has the ability to solve JSP. In short, the research of JSP is still in its infancy, and JSP still has a lot of room for development. Improving existing optimization algorithms and developing new optimization algorithms are key issues in the future JSP field.

Acknowledgments
This work was financially supported by China Agriculture Research System of MOF and MARA (CARS-24-D-01) and China Postdoctoral Science Foundation (2019M662410).

References
[1] Jiang Tianhua. Flexible job shop scheduling problem with hybrid grey wolf optimization algorithm[J]. Control and Decision, 2018,033(003):503-508.
[2] Huang Xuewen, Zhang Xiaotong, Ai Yaqing. ACO integrated approach for solving flexible job-shop scheduling with multiple process plans[J]. Computer Integrated Manufacturing Systems, 2018,24(03):558-569.
[3] Liu Hongming, Zeng Hongyan, Zhou Wei, et al. Optimization of job shop scheduling based on improved particle swarm optimization algorithm[J]. Journal of Shandong University (Engineering Science), 2019,49(01):75-82.
[4] Ronghua Chen, Bo Yang, Shi Li, et al. A self-learning genetic algorithm based on reinforcement learning for flexible job-shop scheduling problem[J]. Computers & Industrial Engineering, 2020,149(1993):106778.
[5] Zhao Shikui, Wang Linrui, Shi Fei. A review of job shop scheduling problem[J]. Journal of University of Jinan(Science and Technology), 2016,30(01):74-80.
[6] Peng Jiangang, Liu Mingzhou, Zhang Mingxin, et al. Review on Scheduling Algorithms for MOFJSF[J]. China Mechanical Engineering, 2014,25(23):3244-3254.
[7] Karaboga D. An idea based on honey bee swarm for numerical optimization, TR06 [R]. Kayseri, Turkey: Erciyes University, 2005.
[8] Zhou Kai, Wen Yongzhao, Wu Wanying, et al. Cloud Service Optimization Method Based on Dynamic Artificial Ant-Bee Colony Algorithm in Agricultural Equipment Manufacturing[J]. Mathematical Problems in Engineering, 2020,2020:(1):1-11.
[9] He Yao, Liu Jianhua, Yang Ronghua. Survey on artificial bee colony algorithm[J]. Application Research of Computers, 2018, 35(05):1281-1286.
[10] Paolo Brandimarte. Routing and scheduling in a flexible job shop by tabu search[J]. Annals of Operations Research, 1993, 41(3):157-183.