Ant Colony Algorithm based on Solving Strongly Heterogeneous Container Loading Problem

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Abstract
Container loading problem is a NP complete problem. The strongly heterogeneous container loading is a loading pattern with variety of goods and different size. In the process of loading, it is difficult to solve. This paper studied the strongly heterogeneous container loading problem and proposed an improved ant colony algorithm. It was given efficient encoding, decoding and sequence selection and cross steps and methods for algorithm of the loading problem. It was given execution process of the improved algorithm, and time complexity analysis for the algorithm. Through examples of test results for loading process and comparison the algorithm were concluded to solve the strong heterogeneous container space utilization than other algorithms and show the usefulness and effectiveness of the algorithm.
Key words: STRONGLY HETEROGENEOUS, CONTAINERLOADING, ANT COLONY ALGORITHM, ENCODING, SPACE UTILIZATION RATE

1. Introduction

Container loading problem is complex constraints and issues that need to optimize, which belongs to NP-complete problems. During studying the problem, the beginning phase of the study is focused on solving the one-dimensional and two-dimensional problem, mainly adopt deterministic algorithm. Later stage is mainly analyzed from three-dimensional cutting and layout containers and intelligent optimization algorithms and heuristic algorithms greatly improve loading efficiency [1]. Research objective of container Loading Problem is mainly to meet the high utilization of container under certain constraints, such as from the viewpoint of maximizing the utilization of space or weight and center of gravity of the loading rate aspects. Because of different types and sizes of loading goods, container loading divided into weakly and strongly heterogeneous [2]. Weak heterogeneous mainly solved the less kind of goods, and more number of loading problems. Strong heterogeneous solved smaller number and a variety of sizes and types of goods issue.

Focused on the loading of strongly heterogeneous container the paper mainly adopted the improved ant colony algorithm, which is subdivided into the priority sequence of the container loading space and the placement of the goods. The paper analyzed the space of the container utilization rate as the target function analysis. Firstly considered the volume sorting of the goods, secondly crossed get the optimal sequence consideration into the container the volume of goods corresponding to arbitrary rotation and selection sequence. The biggest feature of the improved algorithm had been the volume of each goods as an inspire pheromone for the study of the algorithm. Firstly search sequence is the biggest target for solving the problem. Secondly, the algorithm was obtained the sequence by searching and crossed the new sequence and the optimal sequence, eventually formed the optimal sequence. The sequence after multiple iterations is the final result of placing the goods.

2. Improved algorithm of ant colony

Ant colony algorithm simulated ants looking for food, which belongs to the modern bionics, through a computer program processing algorithm. To the ant colony algorithm ,Colorni A, Dorigo M and Maniezzo V three scientists in 1992 through observing the ants of looking for food in the process ways fined inspiration, and proposed ant colony in search of food source in the process reflects the optimization ability to solve some optimization problems [4]. This article described the container loading problem as a trigeminal tree structure [5],using the improved ant colony algorithm to solve it and compressed encoding and decoding ;Choosing goods sequence of the program on the basis of information elements in the path of the ants looking for food ;Getting the optimal sequence of ant colony from the optimal program of history and ants find food sequences, which can be used as the optimal sequence of loading goods; The algorithm needs iteration many times [6] and using two different kinds of volatile coefficient to avoid pheromone rapid saturation in the process of ants search, the improved algorithm is more superior to other algorithms.

2.1. Encoding

Using ant colony algorithm to solve the strong heterogeneous container loading problem, first step is to transform the container loading of the goods in the feasible solution space into the search the solution space which ant colony algorithm can process. The solution space of the element represents a series of Numbers.

Designed the algorithm and represented process by numbers of loading the goods is the encoding. The calculated codes are in binary string [7].

To solve the three dimensional loading problem, we should encode the goods first.$\mathrm{p} = (\mathrm{p}_1, \mathrm{p}_2, \mathrm{p}_3, \cdots, \mathrm{p}_\mathrm{n})$, nis the total number of the goods. In the process of encoding, we should consider several issues. First, according to the volume of goods to decide the loading of the goods order and several kinds of randomly placed second goods status also need to consider.

To solve the problem, we should use the remaining available space in the container as the target and choose the goods sequences and state sequences,$\mathrm{p}_\mathrm{i}$is the serial number of the goods,$\mathrm{k}_\mathrm{i}(1 \le \mathrm{k}_\mathrm{i} \le \mathrm{n})$ands$_\mathrm{i}(1 \le \mathrm{s}_\mathrm{i} \le 6)$mean the state of the goods placed.

2.2. Decoding

Decoding and encoding is a process of mutual exclusion. Decoding transformed the solution which searched from the three dimensional solution space into the feasible solution of original problem, and obtained the objective function values from feasible solution.

In the strong heterogeneous container loading problem, according to the specific loading sequence rules to load the actual goods, the objective function value is to compute the largest percentage of the load cargo volume and the container volume [8].

$$\mathrm{v} = \max\left(\frac{x_i \cdot \sum_{i=1}^{n} l_i \cdot w_i \cdot h_i}{V}\right) \quad (1)$$

V is the biggest cubed out of the container, xiis the number of the first cargo loading,l_i, w_i, h_irefer to the dimensions corresponding respectively of the goodi, Vis the volume of a container.

Using the code p and the stack to solve the space problem then obtained the actual loading sequence of the goods, execution as shown in Figure 1.

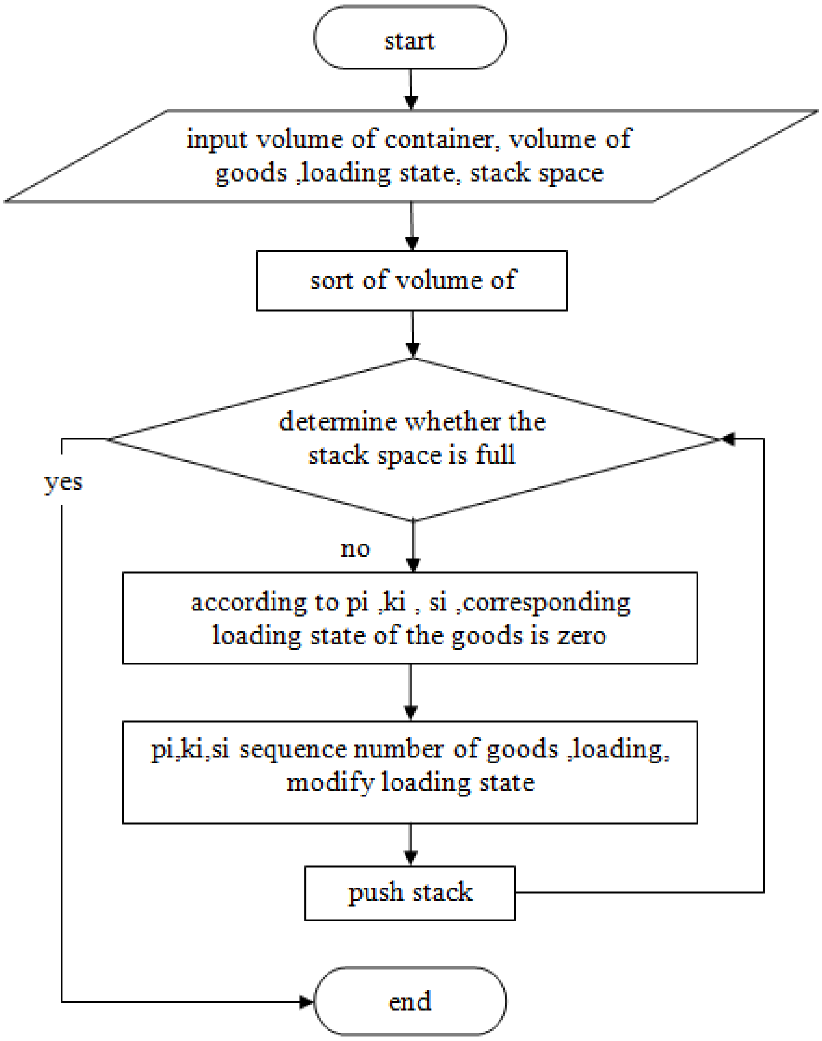

Figure 1. Decoding process

2.3. Selection of Sequence [9]

To choose goods sequence by using the path of the imitating ants searching for food, pheromone and inspiration information. Assume that at a certain timet, an antk, choose 1 package, the serial number of the goods is i, the probability $p_i^k(t)$ as in Eq. (2)[10]:

$$p_i^k(t) = \tau_{i,i}(t) \times v_i \div \left[\sum_{j-1}^{n} \tau_{j,j}(t) \times v_j\right] \quad (2)$$

In Eq. (2), v_i is the volume of the goodsi,$\tau_{i,i}(t)$is the pheromone from the source point to the goods.

$p_i^k(t)$is the probability that the ant k chooses the goods i and then selects the goods j , as in Eq. (3):

$$p_{ij}^k(t) = \begin{cases} \tau_{i,j}(t) \times \dfrac{v_j}{\sum_{U \in N_i^k(t)} \tau_{i,u}(t)} \times v_u & \text{if} \quad j \in N_i^k(t) \\ 0 & \text{otherwise} \end{cases}$$
(3)

In Eq. (3),$\tau_{i,j}(t)$is the pheromone from the goodsito the goods j after a certain time t.

$N_i^k(t)$ is the rest of the goods collection which the ant knot selected after it selected the goodsi at time t.The goods sequence pheromone under initial state as shown in Eq.(4):

$$\tau_{i,j}(0) = \begin{cases} \frac{1}{n} & \text{if } i = j \\ \frac{1}{n-1} & \text{if } i \neq j \end{cases} \quad (4)$$

We can find the state of goods is placed after the goods are selected. If the choice state of goods i is s,the probability is $q_i^s(t)$as in Eq. (5):

$$q_i^s(t) = \frac{\omega_i^s(t)}{\sum_{k=1}^{sn(i)} \omega_i^k(t)} \quad (5)$$

In Eq. (3),$w_i^s(t)$ is the pheromone of the goodsi at the statesand the timet, sn(i) are the state numbers of the goods i, If the goods can be rotated arbitrary, $sn(i) = 6$, the probability of selecting each state is $w_i^s(0) = \frac{1}{6}(s = 1,2,\cdots,6)$).

2.4. Selection of the optimal sequence [15]

The process of selecting the optimal sequence of goods is to cross the optimal history sequence and the arbitrary sequences which produced by simulate ant searching process .It's the corresponding sequence in the loading problem. In order to ensure the effective sequence after cross process, the serial number of the same loaded goods must not be repeated in the cross of the optimal sequence. So we can get the sequence $p1$ and the historical optimal program sequence p^* from the process of ants searching for food .We also can obtain p_2 and p_3 as new sequences after crossing the program sequences. Decoding the sequence p_1, p_2, p_3, take the optimal cross sequence as the new ant search path.

Set the optimal sequence for history as $p^* = \{p_1^*, p_2^*, p_3^*, \cdots, p_n^*\}$ and the current ant search sequence as $p_1 = \{p_{11}, p_{12}, p_{13}, \cdots, p_{1n}\}$. Specific operation of crossing sequence is as follows:

Step 1: Getting the cross element randomly.
$a(1 \le a \le n-2), p_2 = \{p_{11}, p_{12}, \cdots, p_{1a}\}$,
$p_3 = \{p_1^*, p_2^*, \cdots, p_a^*\}$.

Step 2: Detection the sequence $A = \{p_{a+1}^*, p_{a+2}^*, \cdots, p_n^*, p_1^*, p_2^*, \cdots, p_a^*\}$ orderly. Compare the number of goods in the sequence to the number of goods in the sequence p_2 .If two numbers are different then add the element to the sequence p_2 else test the next element till the end.

Step 3: Detection the sequence $B = \{p_{1(a+1)}, p_{1(a+2)}, \cdots, p_{1n}, p_{1(a+1)}, p_{11}, p_{12}, \cdots, p_{1a}\}$ again. Compare the number of goods in the sequence to the number of goods in the sequence p_3 .If two numbers are different then add the element to the sequence p_3, else test the next element till the end.

2.5. The updating of the pheromone [16]

The algorithm uses the ant to update the pheromone in the process of the select goods sequence. Assuming that the optimal sequence in this iteration is far better than the optimal sequence in history, we will need to update the pheromone of corresponding sequence of the goods and the corresponding status of pheromone. We can accord the latest update record and using smaller volatile coefficient to avoid search path information achieving rapid saturation in the process of updating. It assumes the number of the first goods is f, the number of the goods is i, the place status is p_{si}, the numbers of the latter goods is p_{ni}, the optimal sequence of this iteration is $p = \{p_1, p_2, \cdots, p_n\}$, the node p_i's goods number is k_i and status is s_i.

Updating the pheromone of the first good:

$$\tau_{i,j}(t+1) = \begin{cases} (1-\rho)\tau_{i,j}(t) & i \ne k_1 \\ (1-\rho)\tau_{i,j}(t) + \rho & i = k_1 \end{cases} \quad (6)$$

$$\rho = \begin{cases} \rho_1 & k_1 = f \\ \rho_2 & k_1 \ne f \end{cases}$$

ρ_1, ρ_2 are volatile coefficients, $\rho_2 > \rho_1$.

Updating the pheromone of the latter goods:

$$\tau_{k_i,j}(t+1) = \begin{cases} (1-\rho)\tau_{k_i,j}(t) & j \ne k_{i+1}, j \ne k_i \\ (1-\rho)\tau_{k_i,j}(t) + \rho & j = k_{i+1}, j \ne k_i \end{cases} \quad (7)$$

$$\rho = \begin{cases} \rho_1 & k_{i+1} = pn_{ki} \\ \rho_2 & k_{i+1} \ne pn_{ki} \end{cases}$$

Updating the pheromone of the goods' status:

$$\omega_{k_i}^l(t+1) = \begin{cases} (1-\rho')\omega_{k_i}^l(t) & l \ne s_i \\ (1-\rho')\omega_{k_i}^l(t) + \rho' & l = s_i \end{cases} \quad (8)$$

$$\rho' = \begin{cases} \rho'_1 & s_i = ps_{ki} \\ \rho'_2 & s_i \ne ps_{ki} \end{cases}$$

p'_1、p'_2 are volatile coefficients ,$p'_2 > p'_1$.

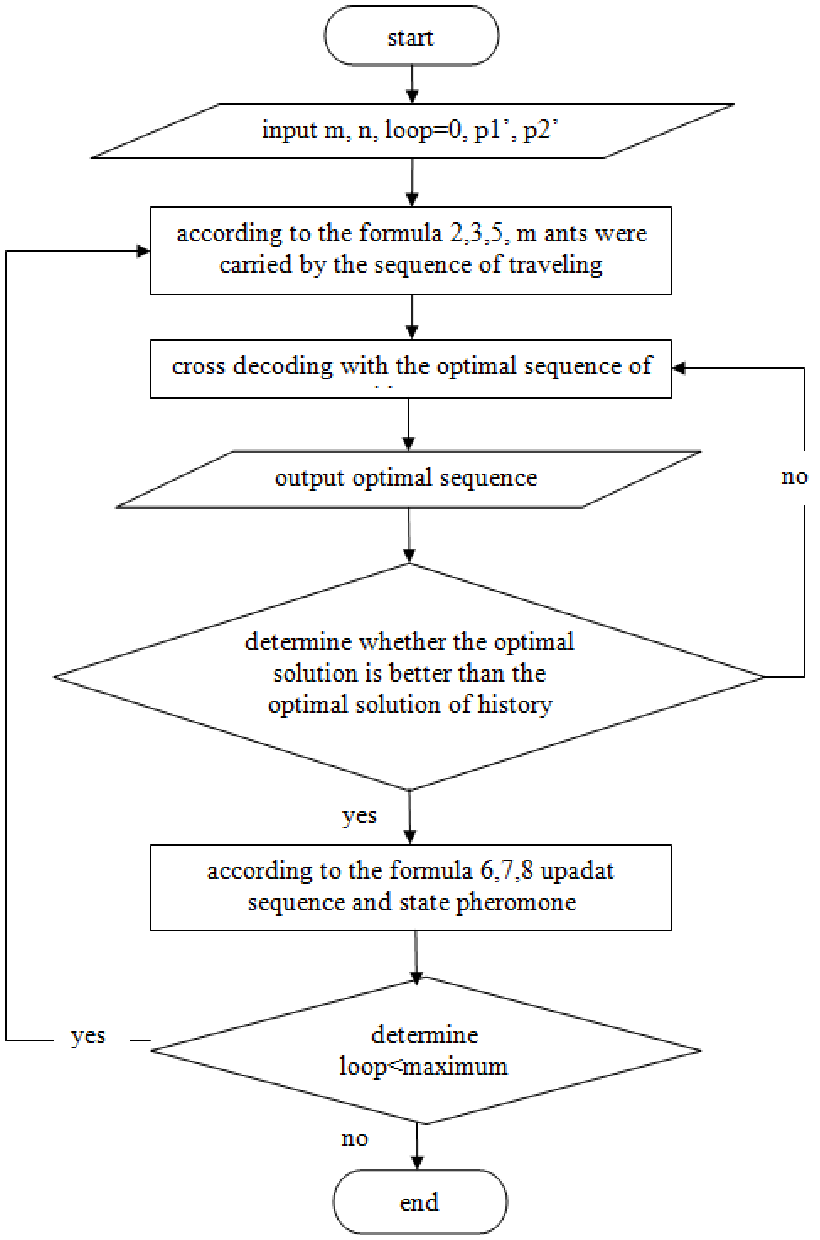

Figure 2. Execution process of the Algorithm

2.6. Steps of algorithm

To solve the strong heterogeneous container loading problem, the execution process of the algorithm as shown in Figure 2.

2.7. The complexity analysis of the algorithm

We assumed the number of ants is m, the number of loading goods is n, the number of iteration is loop. The complexity of the improved ant colony algorithm of solving the goods sequence is $O(n^2)$, the complexity of solving the placement status sequence is $O(n)$, the complexity of crossover sequence is $O(n^2)$, the complexity of goods decoding sequence is $O(n^2)$, the complexity of ant updating pheromone is $O(n^2)$,the complexity of algorithm is $O(loop \times m \times n^2)$.

3. The instance test

The parameters are set as follows : $\rho_1 = 0.06$、$\rho_2 = 0.18$、$\rho_1' = 0.06$、$\rho_2' = 0.12$、$m = 80$、$loop = 650$。

To verify the effectiveness of the proposed algorithm, the size of the container based on the benchmark. The length, width and height are 5.8m,2.4m and 2.4m.The Dimensions of goods based on the data of the reference literature [2] .i means the goods number; l, w, h, v represent the length, width and height, volume of the goods. 30 goods dimension data as shown in Table 1.

Table 1. The size of goods (Unit: m)

i	l	w	h	v	i	L	W	h	v	I	L	w	h	v
1	1.2	2.2	2.2	5.808	11	0.7	1.7	1.0	1.190	21	0.4	1.0	0.6	0.240
2	1.0	2.2	1.8	3.906	12	0.6	1.7	0.8	0.816	22	0.4	0.9	0.6	0.216
3	1.2	2.0	1.6	3.840	13	0.6	1.3	1.0	0.780	23	0.5	0.7	0.6	0.210
4	1.1	2.2	1.2	2.904	14	0.5	1.3	0.7	0.585	24	0.4	0.8	0.6	0.192
5	1.1	2.1	1.2	2.772	15	0.7	1.1	0.7	0.539	25	0.5	0.7	0.5	0.175
6	1.1	1.9	1.2	2.508	16	0.6	1.2	0.7	0.504	26	0.4	0.8	0.5	0.160
7	1.0	1.5	1.4	2.100	17	0.7	0.9	0.7	0.441	27	0.3	0.8	0.5	0.120
8	0.8	1.2	0.6	1.296	18	0.4	1.4	0.7	0.392	28	0.3	0.6	0.3	0.540
9	0.5	1.3	0.9	1.235	19	0.5	1.3	0.6	0.390	29	0.6	0.3	0.3	0.540
10	1.0	1.2	1.0	1.200	20	0.6	0.8	0.7	0.336	30	0.3	0.3	0.6	0.540

The results of loading as shown in Figure. 3.We get the loading plan according to the algorithm; utilization rate of loading space is 85.11%.Compared with reference [19] which loading 17 goods and having 82.7% space utilization and reference [20] which loading 20 goods and having 83.3% space utilization, this algorithm can increase the loading number and get higher space utilization. The algorithm completes the simulation system by C language. The simulation results are shown in Figure. 4, 5, 6 and the effect is remarkable.

ID	Length*Width*Height	Number	Color	Loaded number
1	12*22*22	1		1
2	10*22*18	1		1
3	12*20*16	1		1
4	11*22*12	1		1
5	11*21*12	1		1
6	11*19*12	1		1
7	10*15*14	1		0
8	6*12*8	1		1
9	5*13*9	1		1
10	10*12*10	1		0
11	7*17*10	1		1
12	6*17*10	1		1
13	6*13*7	1		1
14	5*13*7	1		0
15	7*11*7	1		0
16	6*12*7	1		1
17	7*9*7	1		1
18	4*14*7	1		1
19	5*13*6	1		1
20	6*8*7	1		0
21	4*10*6	1		1
22	4*9*6	1		1
23	5*7*6	1		1
24	4*8*6	1		1
25	5*7*5	1		1
26	4*8*5	1		0
27	3*8*5	1		1
28	3*6*3	1		0
29	3*6*3	1		1
30	3*6*3	1		1

Figure 3. The result of cargo loading

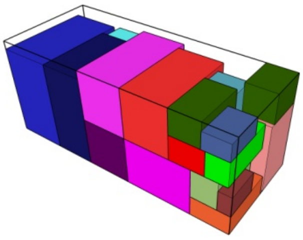

Figure 4. Result 1 of container loading

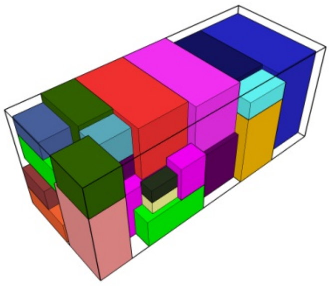

Figure 5. Result 2 of container loading

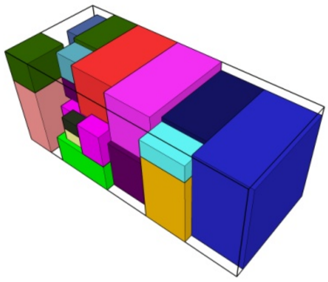

Figure 6. Result 3 of container loading

4. Conclusions

In view of strong heterogeneity problems of container loading, the improved ant colony algorithm was proposed. The algorithm introduced a series of process of the algorithm implementation, gave the steps of the algorithm and analyzed the algorithm complexity. We got a reasonable layout and loading scheme through a container loading case. The scheme showed the practicability and validity of the algorithm and improved the space utilization rate of the container and efficiency of container loading.

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