Research on Three-Dimensional Packing Model and Analysis of Spatial Algorithms for Distribution Center

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Abstract. The B2C retail e-commerce logistics center is constantly developing towards the intelligence and unmanned direction. In the automatic packaging, there are problems of low efficiency and low utilization of box volume caused by packing algorithm. The current common spatial analysis algorithm and three-dimensional packing algorithm and so on are analyzed. Based on the above analysis and combined with the order characteristics of retail e-commerce, a three-dimensional packing model of multi-box with multi-commodity is established. Hybrid Genetic Algorithm and MATLAB are used to solve the model and its solution method are verified by a retail e-commerce data.

Keywords: Three-dimensional packing model, Spatial analysis, Heuristic Algorithm, Genetic Algorithm.

1. Introduction

In the traditional B2C (Business-to-Customer) (business-to-customer e-commerce model) retail e-commerce logistics center, in the process of packaging small items, the system will automatically recommend packaging cartons based on the volume and shape of the product. But in the long-term data according to statistics, it is found that the packaging carton recommended by the fuzzy relationship between the total volume of the product and the carton volume is inaccurately, some product even fail to pack properly. The second re-selection will not only waste the carton volume, but also greatly increase activity cost, so designing a reasonable packing algorithm is the basis of packing.

Aiming at the problem of boxing and packing, scholars at home and abroad have done a lot of research on the boxing heuristic algorithm. G-eorge and Robinson first proposed the most representative heuristic algorithm based on the concept of "layer"; Gehring is proposed a new heuristic algorithm by layer layout, which has significantly improved the space utilization and center of gravity balance problem; Gehring H innovatively applied the genetic algorithm to the three-dimensional boxing problem by establishing a multi-dimensional model genetic algorithm; David Pisinge proposed the container heuristic loading method. The heuristic loading method divides the space according to the method of layering and then stripping, and uses the branch and bound method to divide the layers and strips, which is applied to the solution of large-scale packing problem; The algorithms published by Paquay, Jamrus, Araya have also made good progress in the study of boxing.
The innovative co-evolutionary algorithm proposed by domestic scholar Zhang Xinzheng guarantees the competitive quality of the population and accelerates the convergence rate of the solution; the concept of "sub-space" proposed by Jin Zhihong performs space based on the heuristic algorithm, is divided to improve the loading efficiency, in addition, Li Suncun, Zhang Yajian and others have also achieved good results in the study of packing problems.

2. The establishment of three-dimensional packing model

2.1. Analysis of spatial algorithms
Reasonable division of cabinet space is a prerequisite to ensure the utilization rate of space. The common space divisions are as follows. (1) The division space method of layering and then drawing bars has a better optimal solution in the solution of mixed cargo, but it will generate more trivial space; (2) Trident tree space segmentation method, the reasonable placement of goods will optimize the utilization of space, but the unreasonable space division may cause the entire space to be improperly arranged; (3) The three-space segmentation method, performs a space search on the basis of the original cargo to reduce the complexity of space division, and merges the generated trivial space as necessary.

In the process of packing, the shape of the remaining space inside the box becomes complicated. In order to simplify the space and improve the utilization rate of packing, the space is divided by three-space segmentation method. When the goods are loaded, the remaining boxes are divided into the front, right and upper three spaces, and the continuous loading of goods will continue to generate the above subspaces until the box is full or there are no goods to be loaded.

2.2. Product size analysis
Generally, the volume of goods in B2C retail e-commerce distribution centers is small, and the specifications of the goods are already known at the time of the customer's order. Analyze of historical order data, and use the probability statistics method to find the total volume distribution of a single order.

2.3. Establishment of packing model

2.3.1. Problem description
Given i goods, the length, width and height are recorded as li, wi, hi into the length, width and height Lj, Wj, Hj in the box, uncertain factors are considered. Therefore, certain parameters are constrained: (1) mass constraints, (2) volume constraints, (3) load constraints (4) orientation constraints: the direction of placement is restricted for specific goods.

2.3.2. Model establishment
Build a packing model with optimization rate as the target to solve the complex packing problems.

(1) The optimization rate of packing volume is the objective function:

$$Z = \max \frac{\sum_{i=1}^{s} v_i}{V_j}$$

In the formula: Z represents the utilization of the box; vi represents volume of No.i cargo; Vj represents the volume of the box.

(2) Volume constraints of the cargo

$$\sum_{i=1}^{s} v_i < V_j$$

vi represent volume of No.i cargo, Vj represent No.j volume of box.
3. Weight constraint of the cargo

\[ \sum_{i=1}^{5} m_i < M_j \]

\( m_i \) represent No.\( i \) Weight constraints of the cargo, \( M_j \) represent No.\( j \) the maximum mass that a box can withstand.

4. Size constraints of the cargo

\[ 0 \leq x_i + y_i \leq L_i \]
\[ 0 \leq y_i + w_i \leq W_i \]
\[ 0 \leq z_i + h_i \leq H_i \]

\( x_i, y_i, z_i \) is the reference coordinates of the reference point, \( l, w, h \) represents the length, width and height of the cargo, \( L, W, H \) represent the length, width and height of the box.

2.4. Solution of the model

2.4.1. Selection box volume. In order to improve the utilization of packing and packing, the volume of the box must be the smallest while satisfying the goods. Consider whether a single box to fill or multiple boxes to pack the product, and the box type and volume are numbered.

2.4.2. Heuristic algorithm. This paper uses a combination of heuristics algorithms and genetic algorithms to solve the problem. First of all, heuristic algorithms are used to provide the initial solution group for genetic operation to ensure that the initial population for genetic operation has the solution; Then the heuristic sequencing strategy is used to determine the priority of the cargo placed in the packaging tray in the initial solution group of the genetic algorithm; the second positioning strategy is to determine the placement of the cargo in the current remaining space of the carton, and finally the three-space segmentation method is used to divide the space.

2.4.3. Selection process of box adaptation. During each cargo packing process, the volume of the box is searched for space. While ensuring the box is loaded, the volume of the box is minimized. The flow chart of the box is shown in Figure 1:
2.4.4. Genetic algorithm solution. The basic operation of genetic algorithm is performed, and MATLAB algorithm is used to iterate the algorithm and get the approximate optimal solution.

3. Ease verification
Collect the product and order data of a B2C retail e-commerce company, and organize and statistically analyze the packaging data and find that according to the original algorithm, the success rate of determining the box type is only 50%. the packing algorithm is optimized to improve the success rate and volume utilization rate.

3.1. Dimensions of packing carton
There are 5 types of cartons in the e-commerce distribution center, as shown in Table 1. Sort the volume of the boxes in ascending order and number them j, among them j= (1,2,3,4,5).
Table 1. Carton volume parameters

| Box number | length/m | width/m | high/m | Load-bearing/kg | volume/m³ |
|------------|----------|---------|--------|-----------------|-----------|
| 1          | 0.2      | 0.18    | 0.1    | 1.5             | 0.0036    |
| 2          | 0.25     | 0.2     | 0.18   | 3               | 0.009     |
| 3          | 0.3      | 0.25    | 0.2    | 5               | 0.015     |
| 4          | 0.36     | 0.3     | 0.25   | 10              | 0.027     |
| 5          | 0.53     | 0.32    | 0.23   | 15              | 0.039008  |

3.2. Commodity size analysis and processing
The volume parameters of the cargo are summarized in an Excel table. As shown in Figure 2, the volume of the cargo is analyzed, the volume of a single commodity is mostly smaller, the size of the box is much larger than the size of the cargo, so all the goods can pass Packaging in one go.

![Figure 2](image)

3.3. Solving the model

3.3.1. Preprocessing of coding
(1) Cargo Code: The type of cargo is coded, the code is: i=1,2 ..., n.
(2) Direction coding: In this article, there is no restriction on the direction. You can allow free rotation and placement, and encode the direction of rotation, as shown in Table 2. The number of populations and the number of iterations, and the population mutation operator are as follows:

```matlab
N=5;
N_chrom=6;
iter=500;
mut=0.2;
acr=0.2;
best=1;
chrom=zeros (N, N_chrom);
fitness=zeros (N, 1);
fitness_ave=zeros (1, iter);
fitness_best=zeros (1, iter);
chrom_best=zeros (1, N_chrom+1);
```
Table 2. Placement corresponding to coding

| Placing method | l_i-x-h_i-y | l_i-y-W_i-x | l_i-x-h_i-y | l_i-y-h_i-x | W_i-x-h_i-y | W_i-y-h_i-x |
|----------------|-------------|-------------|-------------|-------------|-------------|-------------|
| coding         | 1           | 2           | 3           | 4           | 5           | 6           |

Take one of the placement methods as an example, the way of placement of code 1 li-x-hi-y, the length of the cargo edge is close to the x-axis, the height edge is close to the y-axis.

3.3.2. Individual encoding and decoding. Coding: Encode the cargo in order, taking into account the loading order, the placement position and the direction of rotation to obtain the following string:

\[ S = \{ a_1, ..., a_i, ..., a_n, a_{n+i}, ..., a_{2n}, a_{2n+i}, ..., a_{3n} \} \]

\( a_1-a_n \) represent the type of cargo, \( a_{n+i}-a_{2n} \) represent the location of cargo, and genes \( a_{2n+i}-a_{3n} \) represent direction of rotation of cargo.

Decoding: There is a one-to-one correspondence between \( a_i, a_{n+i}, a_{2n+i} \) and chromosomes in the gene. That is, the rotation direction of the \( a_i \) cargo is indicated by \( a_{n+i} \). Into the packing carton, a \( a_{2n+i} \) indicates the placement location except the first object.

The genetic algorithm of the population algorithm to find the most reasonable placement position in the box is as follows:

```plaintext```
for i=0:4
    I=i+1;
    chrom=initialize;
    r=chrom(i,:);
    if r==[1,2,0,1,3,3]
        fit=0.715
    else if r==[1,2,0,3,1,1]
        fit=0.715
    else if r==[1,2,0,3,1,3]
        fit=0.501;
    else fit=0;
```

3.3.3. Solving genetic algorithms. The algorithm is deducted under the conditions of the population number \( N=5 \) and the maximum number of iterations \( T=500 \). The population fitness obtained through the simulation experiments of MATLAB is shown in Figure 3. The utilization rate of the box space has reached 72%. Compared with the traditional algorithm, the space utilization rate is greatly improved. Through the above experimental data, the hybrid genetic algorithm in this paper has obtained an ideal loading solution in solving the three-dimensional packing problem, both in term of space optimization and utilization rate. There is a significant improvement, proving that the algorithm is suitable for solving 3D boxing problems.
4. Conclusion
Aiming at the background of a retail e-commerce with low packing efficiency and low utilization of cartons, a heuristic algorithm is proposed to solve the complex three-dimensional packing problems. Through the establishment of multi constraint three-dimensional packing model, the reasonable division of space and the use of specific coding methods to code the goods, the hybrid genetic algorithm is used to solve the model and the good space utilization rate is obtained through the loading test of the example goods, which provides an effective method for solving such complex packing problems.

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