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Research on Emergency Supplies Distribution Problem based on Vehicle-UAV Cooperative Path Optimization

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Abstract

Aiming at the problem of emergency supplies distribution in the 5G network environment, this paper solved the optimization scheme of vehicle UAV cooperative distribution through the cooperative operation of vehicles and drones, aiming at solving the problem of emergency supplies distribution in emergencies.The greedy algorithm was used to split the overall distribution optimization problem into single collaborative distribution optimization, and the K-means clustering algorithm was used to divide the single path optimization subgraph.For single path optimization, the optimal goal is to minimize the single path planning distance in the optimization subgraph, and the hybrid integer programming model is solved by genetic algorithm. The application of the model can provide a better solution for the distribution of emergency supplies.

Keywords

Cooperative Path Optimization; K-Means Clustering Genetic Algorithm; Problem of Emergency Supplies Distribution.

1. Introduction

When some major emergencies, such as earthquake, tsunami, volcanic eruption, debris flow and so on, the distribution of emergency supplies is an important link to ensure people's normal life[1].The occurrence of emergencies will often cause road blocking, damage, closure and other unexpected circumstances, greatly affecting the normal material transport.With the rapid development of science and technology and the gradual popularization of 5G network, the uav market is developing rapidly and the technology is becoming increasingly mature[2]."Delivery vehicle + UAV" has gradually become a new and effective delivery method.During the delivery process, the UAV and the delivery vehicle can carry out the delivery tasks synchronously. After the delivery, the UAV can return to the delivery vehicle to load new supplies and replace the battery.This distribution mode can greatly improve the distribution efficiency of emergency supplies, drones can be very good in complex road conditions for material distribution, to prevent secondary disasters caused by secondary injuries to personnel.Aiming at the cooperative working mode of UAV and delivery vehicles[3], this paper establishes the cooperative distribution mode of delivery vehicles and UAV to realize the distribution of emergency supplies in different locations. On this basis, a mathematical model is established to provide support for the establishment of the optimal distribution scheme[4].

2. Establishment of Mixed Integer Programming Model

2.1 Shortest Path and Clustering Algorithm to Draw Molecular Map

Based on greedy strategy, divide the problem into several single path optimization problems[5].The clustering algorithm is used to divide the molecular graph, and the clustering algorithm is combined with the shortest path to divide the subgraph of single path optimization.Firstly, the shortest path

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between nodes is calculated based on the weight data of Annex 2. The model is calculated for the shortest path of unauthorized graph, and the number of designed nodes is small. Therefore, this paper uses the shortest path algorithm to calculate the shortest path between each node, so as to help the effective division of single path optimization subgraph. $Floyd$.

$Floyd$ Algorithm principle (find the shortest circuit between any two points) :

(1) Assign initial value: to all; $i, j, d(i,j) \leftarrow w(i,j), d(i,j) \leftarrow w(i,j), r(i,j) \leftarrow j, k \leftarrow 1$.

(2) Update, for all, if, then; $d(i,j)$ $r(i,j)$ i j $d(i,k)+d(k,j) < d(i,j)$ $d(i,j) \leftarrow d(i,k)+d(k,j)$ $r(i,j) \leftarrow k$.

(3) If, stop. $k = v$ Otherwise, go to (2). $k \leftarrow k+1$.

Note: Input: weighted adjacency matrix; $w(i,j)$ $d(i,j)$: the shortest distance to; i j $R(i,j)$: to the insertion point. i j .

Calculate the shortest distance between nodes and establish the distance matrix:, i j d_{ij} $D = (d_{ij})_{14\times 14}$.

Calculate the shortest distribution path from node to node and establish the shortest path matrix: i j $T = (t_{ij})_{14\times 14}$.

By using the above algorithm and combining with the shortest paths between nodes, the single collaborative distribution subgraph can be determined by clustering the shortest path matrix. $Flody$ K-$means$ The algorithm is a classical algorithm in cluster analysis, which is simple, fast and scalable.For large amounts of data (as in this case), the algorithm is simple and highly efficient. K-$means$.

To sum up, according to the applicability and obvious advantages of the algorithm in cluster analysis, this paper chooses the algorithm for cluster analysis. K-$means$ K-$means$.

The first step of applying the above data to clustering is to go through preliminary variable screening and feature variable extraction, so as to reduce the dimension of clustering data and greatly reduce the time complexity of algorithm execution.For the selection of initial variables, considering the degree of similarity between cases, Pearson correlation analysis was used to refine the variables, and relevant literature was referred to.Finally, several initial variables which can determine the similarity of cases are determined.Using the PCA dimensionality reduction model established in question 1, feature variables were extracted from the initial variables, and then feature variables after dimensionality reduction were clustered.

The formal description of the algorithm is given as follows: K-$means$.

Input: data set with 1 data object, the number of clusters in the clustering result is, and the value is determined according to the elbow principle, i.e. $n*m$ k k k In the process of increasing the value, the value corresponding to the position where the improvement effect of distortion degree decreases the most is the elbow. k .

Output: the number of clusters satisfying the criterion function. k .

The data processing process is as follows:

$Step$ 1: Select any object in the data set, and make each data object represent the center of the initial cluster; k .

$Step$ 2: Divide the remaining data into clusters closest to the data itself;

$Step$ 3: Compute the mean value of each cluster repeatedly to obtain the new cluster center value;

$Step$ 4: Repeat 2 and 3 until each cluster does not change or the objective function converges.

By traversing the value of K according to the elbow rule, the standardized data clustering results of the shortest path matrix can be obtained as follows.When the value of K ranges from 2 to 9, the effect diagram of clustering effect and class cluster index is shown in Figure 1.

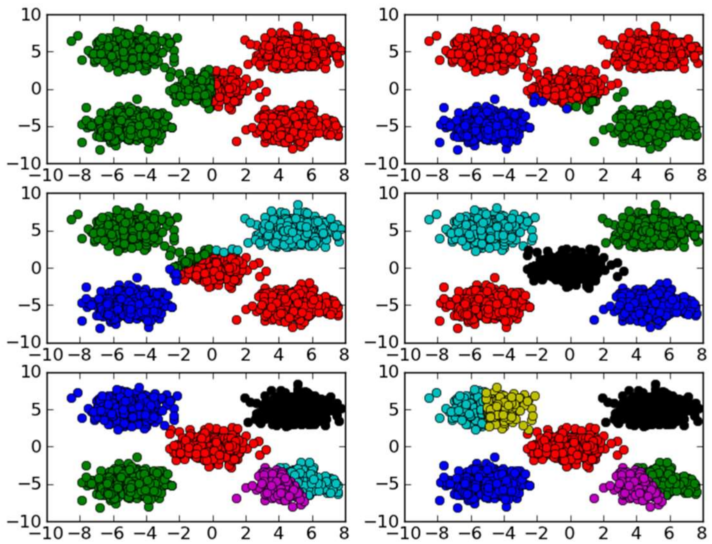

Figure 1. Clustering effect diagram when the value of K ranges from 2 to 7

According to above can get the choice of different clustering cluster center, for clustering effect is different, but the best choice, in this paper, according to the change of class cluster indicators to further determine the initial clustering cluster number, finally using elbow criterion to determine the final clustering three clusters, namely single collaborative distribution optimization subgraph can be divided into 3 pieces. By optimizing each undirected subgraph for a single time, the path optimization results of each link are obtained.The final subgraph is shown in Figure 2.

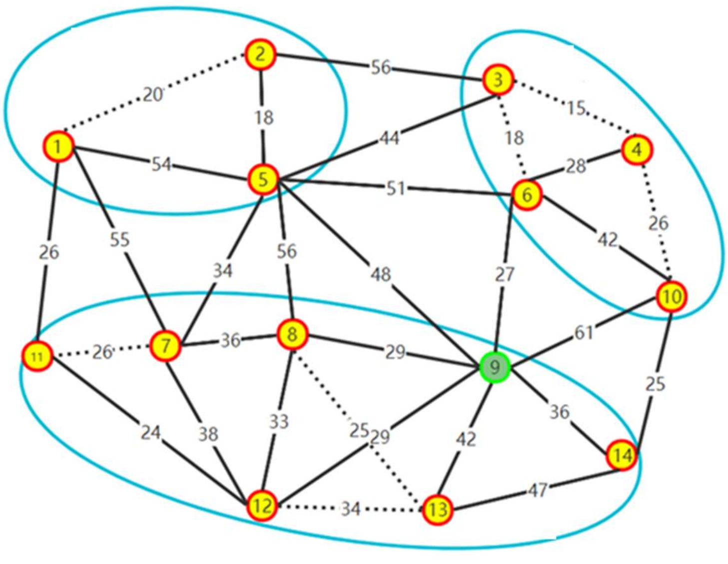

Figure 2. Subgraph division of single path optimization based on greedy strategy

According to the figure above, the subgraph can be used as a single optimization set for cooperative path optimization of uAVs, so as to obtain the optimization results of uAVs and vehicles on the subgraph.

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2.2 Establishment of Cooperative Complex Path Optimization Model of Vehicle-UAV

For single path optimization, further improvement is needed on the basis of the optimization model established in question 1. First, the decision variable is added to the distribution path of UAV, and the optimization goal is to minimize the single path planning distance in the optimization subgraph.The design constraints include uav load constraints, flight time constraints, flight distance constraints, UAV visit distribution point order constraints and uav waiting cooperative constraints, etc.On the basis of improving the single uav path planning model, the overall path optimization model can be further established.The end point recorded in a single delivery path is taken as the starting point of the next delivery path, and the single delivery path optimization iteration of the subgraph is repeated, and the total delivery distance is taken as the optimization target of the overall delivery optimization model, so as to improve the collaborative delivery optimization model of vehicle UAVs.For such a NP-hard model with a large number of nodes and a large number of decision variables, it is basically impossible to optimize the precise algorithm. Therefore, this paper tries to use a variety of heuristic algorithms for intelligent optimization, so as to solve the approximate optimal solution of the collaborative path optimization model for this problem.

Step1: mark special points.For all customer demand points, the vehicle can be delivered.As uav has maximum load limit and maximum flight distance limit in a single flight, the nodes exceeding the maximum load limit of UAV among all customer demand points are marked as; L_m The node exceeding the maximum flight distance limit of uav is marked as. L_d All the marked points can only be delivered by the vehicle, but the marked nodes can be used as the end points of a single arrival of the UAV under the condition of meeting the flight distance limit of the UAV. L_{m} .

$$\sum_{k\in K}\sum_{j\in S_1, i\neq j} y_{ij,k} = 1, \forall i \in L_m \bigcup L_d \tag{1}$$

$$\sum_{k\in K}\sum_{i\in S_1, i\neq j} y_{ij,k} = 1, \forall j \in L_m \bigcup L_d \tag{2}$$

$$\sum_{k\in K}\sum_{j\in S_1, i\neq j} x_{ij,k} = 1, \forall i \in L_d \tag{3}$$

$$\sum_{k\in K}\sum_{i\in S_1, i\neq j} x_{ij,k} = 0, \forall j \in L_d \tag{4}$$

$$0 \le \sum_{k\in K}\sum_{j\in S_2, i\neq j} \left(x_{ij,k} + y_{ij,k}\right) \le 2, i = n+1 \tag{5}$$

$$0 \le \sum_{k\in K}\sum_{i\in S_2, i\neq j} \left(x_{ij,k} + y_{ij,k}\right) \le 2, j = n+1 \tag{6}$$

$$n_k^{(t)} \ge 1, \forall_k \in K \tag{7}$$

Equations (1) and (2) ensure that the marking point must be delivered by the vehicle;Equations (3) and (4) indicate that the customer points marked as will not be delivered by UAV. L_d Equations (5) and (6) indicate that uav and vehicle can enter and exit independently from the distribution center, or uav can be carried by vehicle to enter and exit together.Formula (7) means that the vehicle serves at least one customer point every time it is delivered.

Step2: single path planning.Due to the power limitation of UAV, as much as possible customer demand points should be allocated to UAV within the radius of the furthest flight distance and the maximum load limit of UAV, so as to improve the full load rate and endurance utilization rate of

UAV.For a given flight radius, the maximum number of customer points that uav can serve in a single delivery is limited, and the destination of the next delivery is recorded after each delivery.The power needs to be replenishment after the delivery of UAV. For safety reasons, it is not allowed to hover and wait at the parking point, so the vehicle must arrive before the arrival of UAV.The end point of the single path planning record of the UAV is the end point of the delivery of the vehicle. On the premise of meeting the arrival in advance, as many customer demand points are allocated to the vehicle as possible.Due to the limitation of delivery time, the maximum number of customer points that the vehicle can serve in a single delivery is limited.

$$Min \sum_{i \in S_3, i \neq j} \sum_{j \in S_3} \left(x_{ij,k} + y_{ij,k} \right) \mathrm{d}_{ij}, \forall_k \in K \tag{8}$$

$$S.T. \begin{cases} \sum_{i \in S_3, i \neq j} \sum_{j \in S_3} x_{ij,k} m_i \leq M, \forall_k \in K & (9) \\ \sum_{i \in S_3, i \neq j} \sum_{j \in S_3} x_{ij,k} d_{ij} \leq D, \forall_k \in K & (10) \\ \sum_{i \in S_3, i \neq j} x_{ij,k} \leq 1, \forall j \in S_3, k \in K & (11) \\ \sum_{j \in S_3, i \neq j} x_{ij,k} \leq 1, \forall i \in S_3, k \in K & (12) \\ \frac{\varepsilon}{v^{(t)}} \sum_{i \in S_3, i \neq j} \sum_{j \in S_3} y_{ij,k} d_{ij} \leq \frac{1}{v^{(u)}} \sum_{i \in S_3, i \neq j} \sum_{j \in S_3} x_{ij,k} d_{ij}, \forall k \in K & (13) \\ \sum_{i \in S_3, i \neq j} y_{ij,k} \leq 1, \forall j \in S_3, k \in K & (14) \\ \sum_{j \in S_3, i \neq j} y_{ij,k} \leq 1, \forall i \in S_3, k \in K & (15) \\ S_3 = S_3 - C_k^{(u)} - C_k^{(t)}, \forall k \in K & (16) \end{cases}$$

Formula (8) minimizes the sum of the path distance of vehicle and UAV in single optimization; Formula (9) Ensure that the weight of goods carried by uav at a single time does not exceed the maximum carrying weight of UAV;Formula (10) Ensure that the total distance of a single uav delivery does not exceed the maximum flight distance of uav;Equations (11) and (12) indicate that in all unserved customer nodes, uav does not enter or leave this node more than once.Formula (13) Ensure that the vehicle must arrive before the UAV lands;Equations (14) and (15) indicate that among all unserved customer nodes, vehicles enter and exit this node no more than once.Formula (16) ensures that the customer nodes of a single service are removed from the previous set of unserved customer nodes after each allocation.

Step3: Overall path optimization.Take the end point recorded in a single delivery path as the starting point of the next delivery path, repeat Step2 until all customer demand points are delivered.The delivery distance of vehicle and UAV was added together, and the shortest total delivery distance was taken as the objective function to optimize the route selection of each delivery.

$$\min Z = \sum_{k \in K} \sum_{i \in S_1, i \neq j} \sum_{j \in S_1} \left(x_{ij,k} d_{ij} + \varepsilon y_{ij,k} d_{ij} \right) \tag{17}$$

$$\sum_{k\in K}\sum_{i\in S_1,i\neq j}\left(x_{ij,k}+y_{ij,k}\right)=1,\forall i\in P_{non} \tag{18}$$

$$\sum_{k\in K}\sum_{j\in S_1,i\neq j}\left(x_{ij,k}+y_{ij,k}\right)=1,\forall j\in P_{non} \tag{19}$$

$$\sum_{k\in K}\sum_{j\in S_1,i\neq j}x_{ij,k}=1,\forall i\in P_{start} \tag{20}$$

$$\sum_{k\in K}\sum_{i\in S_1,i\neq j}x_{ij,k}=1,\forall j\in P_{start} \tag{21}$$

$$x_{ij,k}\in\{0,1\}\,\forall i\in S_1;j\in S_1;k\in K \tag{22}$$

$$y_{ij,k}\in\{0,1\}\,\forall i\in S_1;j\in S_1;k\in K \tag{23}$$

Objective function formula (17) is to minimize the total distribution distance between UAV and vehicle.Equations (18) and (19) indicate that all non-docking customer nodes are only delivered by UAV or vehicle once.Formula (20) represents the uav launching node where the UAV only flies out once;Formula (21) represents that the UAV recovery node only lands once;Equations (22) and (23) give the value range of parameters.Equations (6), (7) and (21) jointly give the entry and exit rules when the distribution center is used as the uav sending and receiving point or non-stopping point. The UAV can be launched and recovered from the distribution center or carried in and out by vehicles. During the process, neither uav nor vehicle will visit the distribution center again.

For the above complex collaborative path optimization model, it is difficult to be solved by precise optimization algorithm, so some heuristic algorithms are needed to solve approximate solutions.

3. Genetic Algorithm Solving Mixed Integer Programming Model

This paper mainly uses heuristic algorithm for optimization.The solution is a combination of inherited genes.In order to reduce the number of combinations, the center of the image is divided into blocks.Each piece was regarded as a gene and combinatorial optimization calculation was carried out.

The specific implementation steps of genetic algorithm are as follows:

Step 1: the parameter range of the problem will be required to evaluate and code it;

Step 2: random generation of a population consisting of multiple individuals;

Step 3: Decode all individuals in the population, and then solve the fitness function through the decoded parameters.To assess individual fitness;

Step 4. Judge the convergence conditions. If the optimal solution is found, the convergence selection will be stopped, so that more and more individuals with larger fitness value will be eliminated, while those with smaller fitness will be eliminated.

Step 5: crossover, so that two individuals with a certain probability of crossover operation;

Step 6: variation, so that an individual with a certain probability of mutation operation, so that individual characteristics change;

Step 7: repeat 3 to 7 until the parameters converge.

The image of objective function and iteration times is shown in Figure 3.

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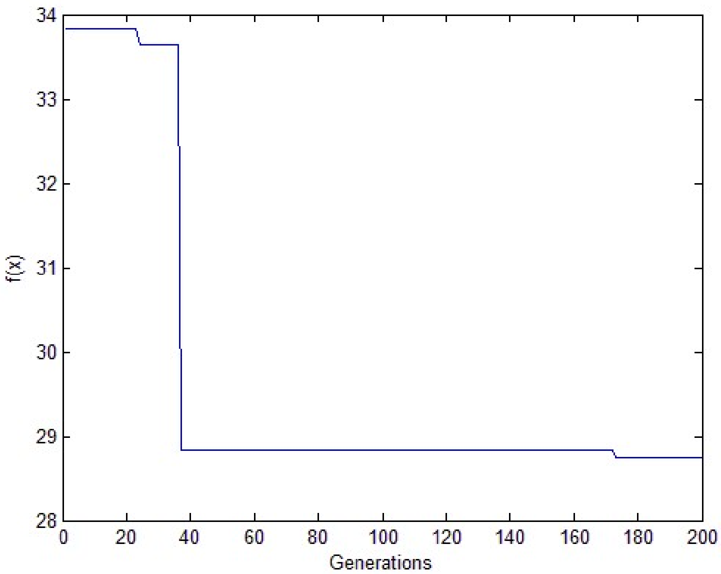

Figure 3. Convergence of genetic algorithm fitness function

According to the relationship between objective function and iteration times, it can be found that the genetic algorithm can get the optimal solution after six iterations, so the convergence of genetic algorithm is good.The convergence of the algorithm is related to the iterative process of the algorithm. The iterative process diagram of the genetic algorithm is presented in this paper, and the iterative convergence process of the genetic algorithm is shown in Figure 4.

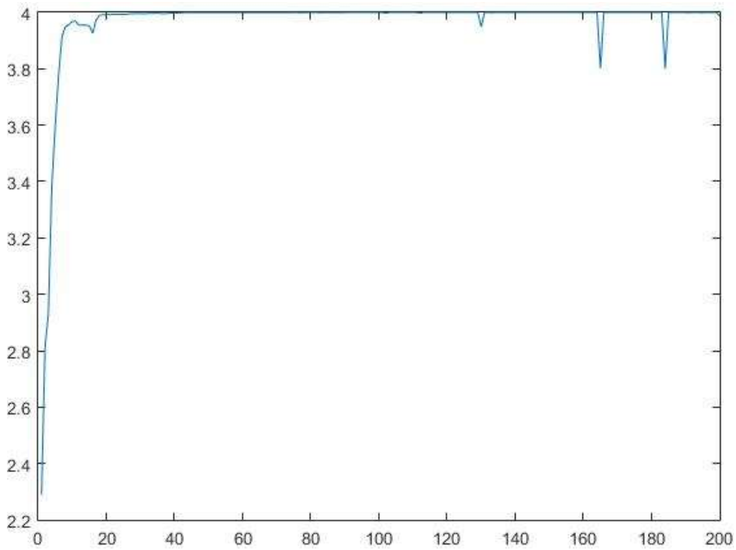

Figure 4. Iterative convergence process of genetic algorithm

As can be seen from the figure, the algorithm converges gradually with the increase of iteration times.It shows that the convergence of genetic algorithm is good.The final solution result is:

Vehicle path: $9 \rightarrow 8 \rightarrow 12 \rightarrow 7 \rightarrow 1 \rightarrow 5 \rightarrow 6 \rightarrow 10 \rightarrow 14 \rightarrow 9$.

Uav path:8→13→12(car following)7→11→1→2→5(car following)→6→3→4→10.

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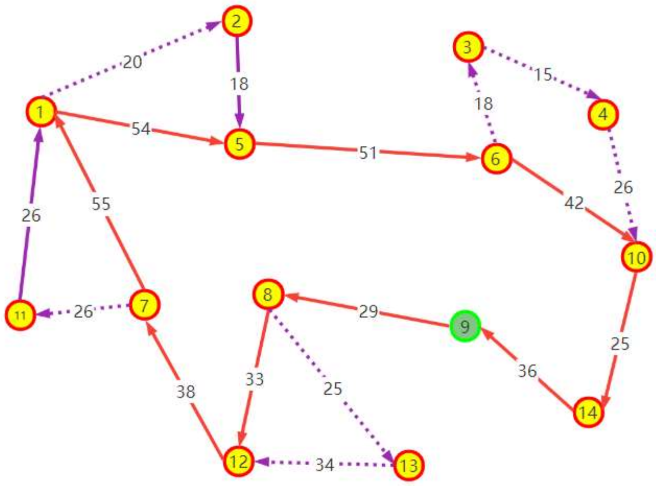

Figure 5. Solution results of path optimization

According to the figure above, we can get a better route plan for the cooperative optimization of vehicle and UAV for the overall delivery. Meanwhile, we can calculate that the overall delivery plan is still 9.61 hours, which not only conforms to the actual operation, but also provides certain basis for the operation optimization of relevant staff.

4. Extension of the Model

In this paper, clustering algorithm is used in the process of path optimization. The goal of cluster analysis is to collect data to classify on the basis of similarity.Clustering comes from many fields, including mathematics, computer science, statistics, biology, and economics.http://baike.baidu.com/view/92404.htmMany clustering techniques have been developed in different application fields. These techniques are used to describe data, measure the similarity between different data sources, and classify data sources into different clusters.http://baike.baidu.com/view/1655430.htmCluster analysis is an effective tool for market segmentation, and can also be used to study consumer behavior, find new potential markets, select experimental markets, and as a pretreatment of multivariate analysis.http://baike.baidu.com/view/2306420.htm.

Clustering comes from many fields, including mathematics, computer science, statistics, biology, and economics.Many clustering techniques have been developed in different application fields. These techniques are used to describe data, measure the similarity between different data sources, and classify data sources into different clusters.From the perspective of practical application, clustering analysis is one of the main tasks of data mining, and can also be used as a preprocessing step of other algorithms.Cluster analysis has important applications in business, biology, geography, insurance and the Internet.

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