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Analysis of UAV path planning effectiveness and evaluation index scores combined with urban logistics scenarios

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Abstract. Using logistics drones for distribution is an optional solution to the problems of saturated logistics industry, insufficient transportation capacity, and high work pressure on employees in real cities. In a realistic urban environment, it is of practical significance to establish a logistics drone path planning model to improve the efficiency of logistics drones by fully considering the multiple requirements of both logistics service parties, such as time and location, and aiming at minimizing transportation costs. Aiming at this problem, this paper analyzes and studies the path planning problem of unmanned aerial vehicles based on the factors that need to be considered in actual life logistics distribution. Firstly, the actual scenario requirements of logistics UAV applications are analyzed and a path planning algorithm for this scenario is enumerated. Subsequently, mathematical models are established from both path planning and customer satisfaction to assess the performance of logistics drones. Then, a comparative analysis of four existing classical path planning algorithms is conducted, and simulated annealing algorithm is used to optimize logistics delivery scenarios for path planning. Finally, combining the mathematical model and simulated annealing algorithm constructed in the previous article, logistics UAV simulation experiments are conducted in urban distribution scenarios and an ideal path planning model is obtained. The work of this article provides a certain reference basis for logistics companies in the application of logistics UAVs and the selection of path planning methods.

Keywords: drone, path planning, simulated annealing algorithm, A* algorithm.

1. Introduction

In today's society, the application of unmanned aerial vehicles (UAVs) is becoming increasingly widespread, both in the commercial and civil fields, where drones can be seen everywhere. UAVs have brought convenience to our daily lives, with specific applications ranging from personal dimensions such as photography and short-haul express logistics to military and civilian applications such as surveying, exploration, and monitoring. Nowadays, the scale of UAVs is constantly expanding, while their technology is also being updated with each passing day. This article has conducted a series of research on the application of unmanned aerial vehicles in the field of logistics.

In China, the "Double 11" is a large-scale online promotional shopping carnival held on November 11th in recent years. Due to the strong promotion efforts of the "Double 11" and the large number of online shopping products for consumers, various express companies have reached a tight situation in

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logistics and distribution before and after the "Double 11". With the continuous improvement of living standards, the scale of China's express delivery business has increased nearly 36 times during the 10-year period from 2010 to 2020. At the same time, during the "Double 11" period each year, the business volume can reach 2-3 times the usual level, but the number of people engaged in the express industry has only increased by 7 times, and the workload of express delivery personnel in their daily delivery has become saturated.

Using drones for logistics distribution extends the transportation path from the ground to the sky. Because the route of drone air delivery is nearly straight, it shortens the transportation distance, avoids the congestion dilemma of couriers on urban roads, and improves delivery efficiency. The use of drones for logistics and distribution has to some extent alleviated the imbalance between the rapid development of the express industry and the slow development of the express industry's personnel [1, 2].

However, currently, there are still many difficulties in using drones for logistics distribution, such as high initial investment costs, the load and endurance of drones that need to be improved, and the unpredictable weather conditions around the world. The path planning and obstacle avoidance capabilities of logistics drones in the process of working are greatly affected by weather factors, among which logistics distribution problems are often described by vehicle routing problems (VRP) [3].

This paper analyzes and studies the path planning problem of UAVs based on the factors that need to be considered in real life logistics distribution. Firstly, the actual scenario requirements of logistics UAV applications are analyzed and a path planning algorithm for this scenario is enumerated. Subsequently, mathematical models are established from two aspects of path planning and customer satisfaction to assess the performance of logistics drones. Then, a comparative analysis of four existing classical path planning algorithms is conducted, and simulated annealing algorithm is used to optimize logistics delivery scenarios for path planning. Finally, a simulation experiment is conducted based on the actual needs of logistics UAV distribution scenarios, and the experimental results are summarized and discussed.

2. Overview of related work

2.1. Actual functional analysis

With the development of science and technology and the progress of society, the cost of human resources has increased. Many countries are experiencing an aging population, and labor resources are becoming increasingly valuable. The development of technology has accelerated the development of the logistics robot industry, alleviated the current situation of personnel shortage in major logistics transfer centers, and improved production efficiency. However, in the context of the continuous development of the scale of online shopping, logistics pressure gradually shifts from logistics transfer centers to urban logistics. In the context of the continuous development of the scale of online shopping, logistics pressure gradually shifts from logistics transfer centers to urban logistics. How to efficiently handle and solve the continuously growing logistics and distribution problems in cities and meet the different distribution needs of various customers has become the focus of attention of relevant industry personnel. The increasingly mature drone technology in recent years has enabled the emergence of drones with various functions, providing a technical foundation for the development of logistics drone research. Using drones for logistics distribution can provide a solution to alleviate the growing distribution pressure in the logistics industry.

2.2. A review of relevant work

Fei Yuhan analyzed the problem of planning transportation paths for unmanned aerial vehicles in urban environments, and developed a logistics unmanned aerial vehicle path planning model based on the operational characteristics and scene locations of unmanned aerial vehicles in the logistics distribution process. Fei Yuhan first used simulated annealing algorithm to solve the UAV delivery order problem. Subsequently, an improved A * algorithm is used to solve the problem of flight paths between various locations. By adjusting the weight coefficients of each objective function, multiple transportation paths

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are obtained, and the optimal path is selected [4]. In his research on obstacle avoidance for unmanned aerial vehicles, Wei Yao proposed an obstacle avoidance algorithm for unmanned aerial vehicles based on a deep cyclic dual Q network. The GRU cyclic neural network module was introduced, and the reinforcement learning priority experience playback mechanism was combined to improve training time and obstacle avoidance success rate [5].

As Dorlin et al. have demonstrated that the load and energy consumption of multi rotor UAVs are linearly related, it is possible to establish a hybrid linear model for the mathematical relationship between the endurance mileage and load of logistics UAVs and for path planning during the distribution process of logistics UAVs at the same time, previous research on path planning for unmanned aerial vehicles mainly focused on military and other fields [6]. However, the urban environment has its unique characteristics, and as a service industry, the logistics industry should also consider factors such as customer satisfaction. Therefore, when studying the path planning problem of logistics unmanned aerial vehicles, its uniqueness should be considered to meet the actual situation and needs.

3. Methodology

3.1. Problem analysis

Two related issues arising from logistics drone distribution. The first is the path planning problem of logistics drones in the distribution process, and the second is the highest overall customer satisfaction problem in the distribution process. The first issue is subject to factors such as drone cost, payload, and endurance in real life. Therefore, in the planning of distribution routes, different distribution sequences should be selected for carrying multiple pieces of goods with different weights. The second issue in real life is the delivery of intra-city express delivery, such as fruits and other goods ordered on some e-commerce platforms. Customer satisfaction is closely related to delivery time [7]. From this, a concept of customer satisfaction can be derived, that is, within a certain time interval, user satisfaction is the highest, and beyond that time interval, customer satisfaction decreases with the extent of exceeding the time interval. Therefore, when planning the distribution path of logistics drones, different emphasis should be placed on distribution costs and customer satisfaction, and comprehensive evaluation should be conducted to obtain the scheme with the highest score and the best comprehensive performance. This section mainly constructs mathematical models for the above two issues and selects two more classical algorithms for comparative analysis.

3.2. Establishment of mathematical models

Due to the characteristic that the endurance of unmanned aerial vehicles is mostly linked to time, and the endurance time decreases rapidly with the increase of load weight, it is more appropriate to use the actual load * time as the transportation cost. At the same time, the latest published performance data of logistics UAVs, represented by small multi rotor UAVs, mostly measure the endurance of such UAVs in terms of time. Therefore, the transportation capacity of logistics drones is represented by "time * load". The equation is expressed as follows:

$$E_i = \eta \frac{M_i \cdot L_i}{v}$$
$$\eta = \frac{(T_e - T_f) Q_U}{T_e T_f M_{max}} \tag{1}$$

Where E_i is the transport energy consumption of the current segment i path UAV, M_i is the load of the UAV on this path, L_i is the path length of the segment, v is the transport speed of the logistics drone, η is the UAV energy consumption coefficient, Q is the battery capacity of the drone, U is the working voltage, T_e is the endurance time when no-load, T_f is the endurance time at full load, M_{max} is the maximum load capacity.

The overall customer satisfaction during the delivery process is an important indicator that determines the quality of logistics drone delivery. The evaluation function designed in this article is set as follows:

$$f(x) = \omega_1 * \sum_{i=1}^{n} Ei + \omega_2 * \sum_{i=1}^{n} Pi \tag{2}$$

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Where $i = \sum_{i=1}^{n} Ei$ represents the transportation cost of logistics drones traversing n distribution locations, $\sum_{i=1}^{n} Pi$ represents the total customer satisfaction penalty for logistics drones based on the set route and delivery order. ω_1, ω_2 represents the importance and business strategy of different logistics companies on transportation costs and customer satisfaction.

3.3. Control the selection of algorithms

The path planning part is one of the key technologies in the entire process of logistics drone distribution, and its performance directly affects the selection of drone travel paths and the smoothness of multiple distribution processes. At the same time, because the quality of the path planning algorithm directly affects the performance of the path planning part, how to choose the appropriate algorithm to quickly plan an efficient path in response to various scenarios and meet the distribution requirements of all parties is a problem that must be solved in the research of logistics unmanned aerial vehicle distribution.

The main algorithms used in global path planning algorithms can be roughly divided into traditional algorithms and intelligent algorithms. This article briefly introduces and compares the performance of Dijkstra algorithm, genetic algorithm, traditional A * algorithm, and simulated annealing algorithm.

The Dijkstra algorithm was proposed by E.D. Dijkstra in 1959. The algorithm adopts a greedy mode, and the next node selected during multiple iterative processes after establishing the initialization node is the nearest child node of the current node, which ensures that the path traveled by each iteration is the shortest [8]. To ensure the shortest final path, the shortest path from the initial node to all traversal nodes must be updated during each iteration.

Genetic algorithm is a classic intelligent optimization algorithm, which uses multiple individuals to equate to the possible solution of the optimization function, and each individual forms a "gene" according to a certain coding method. It evolves the population through operations such as crossover and mutation of genetic operators to select the most suitable individual (optimal path) [9].

The A * algorithm is a heuristic search algorithm that establishes heuristic search rules during the search process to determine the distance relationship between the target location and the real-time search location, and prioritizes the search direction towards the location of the target point, thereby achieving the effect of improving search efficiency [10].

Simulated annealing algorithm is an algorithm based on simulating the process of solid annealing in thermodynamics, which is an extension of local search algorithm [11].

The distribution path cannot only consider the shortest path, but also needs to consider issues such as cost and customer satisfaction. Due to many factors to be considered, this paper selects simulated annealing algorithm to obtain an approximate solution. When applying this algorithm, first set the initial temperature of the system, calculate the evaluation function for the generated initial delivery order, and then recalculate customer satisfaction based on the new delivery order obtained from the disturbance, repeating it multiple times until the set number of iterations is reached. After completing the above operations and determining the distribution order of multiple distribution points, the A * algorithm can be used to solve the minimum cost route from the start point to the end point.

4. Analysis of experimental process and results

4.1. Control the selection of algorithms

Firstly, the following assumptions are made for the evaluation indicators of path planning:

1) The evaluation function is the evaluation result=weight 1 * customer satisfaction + weight 2 * transportation cost. Different weights represent the importance that different logistics companies attach to these two evaluation indicators. The analysis of the results can provide guidance and suggestions for the future path planning of logistics companies. Introduce a concept of customer satisfaction: When the delivery time matches the customer's expected time interval, customer satisfaction is highest. Customer satisfaction decreases as the degree of deviation from the time interval increases.

2) The difference between the transportation cost of UAVs and the transportation mileage used for traditional ground transportation is that the endurance capacity of UAVs is mostly related to time, and

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the endurance time rapidly decreases with the increase of the load weight. Therefore, the actual load * time is used as the transportation cost.

3) The drone must traverse all mission points during the delivery task.

4.2. Experimental results and discussion

Using the real terrain of a city as a reference, randomly select multiple different three-dimensional coordinates within a certain range to simulate the logistics and distribution needs of customers in different locations in a real urban environment. At the same time, due to the different business strategies of different logistics companies, that is, the emphasis on transportation costs and customer satisfaction varies, that is, the weight coefficients that affect customer satisfaction and transportation costs in the text are different. Therefore, for two weight coefficients ω 1 and ω 2 are adjusted. The adjusted multiple experimental results are shown in the table 1.

Table 1. The adjusted multiple experimental results.

ω_1	ω_2	Comprehensive cost	transportation cost	Satisfaction penalty
1.0	0.0	338.19	338.19	1026.12
0.9	0.1	446.13	412.42	749.95
0.7	0.3	537.33	565.08	426.33
0.5	0.5	444.86	594.33	294.47
0.3	0.7	385.12	634.42	278.28
0.1	0.9	282.16	778.90	238.03
0.0	1.0	205.24	903.17	205.24

It is not difficult to see from the data in the table 1 that ω_1 or ω situation at 2=0 is more extreme. Although the overall cost seems small, it does not have practical significance. By analyzing several other sets of data, the data shows ω within the range of 0.7-0.9, both distribution costs and customer satisfaction penalties vary greatly, which means that this range is a sensitive range for parameter adjustment. When ω_1 within the range of 0.3-0.7, the distribution cost has not changed much, but the customer satisfaction penalty has greatly decreased, ω_1=0.3, ω_2=0.7 will become the actual choice for most logistics companies.

5. Conclusion

This paper analyzes and studies the path planning problem of UAVs based on the factors that need to be considered in real life logistics distribution. Firstly, the actual scenario requirements of logistics UAV applications are analyzed and a path planning algorithm for this scenario is enumerated. Subsequently, mathematical models are established from both path planning and customer satisfaction to assess the performance of logistics drones. Then, a comparative analysis of four existing classical path planning algorithms is conducted, and simulated annealing algorithm is used to optimize logistics delivery scenarios for path planning. Finally, combined with the mathematical model and simulated annealing algorithm constructed in the previous article, logistics UAV simulation experiments are conducted in urban distribution scenarios. The experimental results show that when ω 1. Within the range of 0.3-0.7, the distribution cost has little change, but the customer satisfaction penalty has greatly decreased. Due to the limited experimental conditions, there is still a certain gap between the simulation model and the actual working conditions in terms of interference factors. The work of this article provides a certain reference basis for logistics companies in the application of logistics UAVs and the selection of path planning methods. At the same time, the author believes that the study of cooperative operation of multiple unmanned aerial vehicles will be able to solve more practical problems in the path planning of logistics unmanned aerial vehicles.

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