The technical principle and application case analysis of logistics UAV

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Abstract. Driven by multiple factors such as the sharp increase in distribution demand, soaring labor costs, and complex service scenarios, Unmanned Aerial Vehicles (UAVs) have met the basic requirements for practicality and jointly contributed to a "change" in logistics innovation —logistics UAVs. Logistics UAV is one of the typical representatives of the logistics industry's development towards automation and intelligence. After studying two representative logistics and transportation companies in the industry, it was found that the two companies have different positionings for the application scenarios of their respective logistics UAVs, but they have both developed Industry-leading products and technologies through long-term research and development. Although major companies have invested a lot in logistics UAVs in recent years, there are still four major technical problems to be overcome: path planning, automatic obstacle avoidance, battery life and safety. In addition to unavoidable technical problems, factors that hinder the large-scale deployment of logistics UAVs include imperfect commercial markets and imperfect regulatory systems. Although there is still a long way to go for logistics UAVs, logistics UAVs will surely become an indispensable infrastructure for the modern logistics industry in the future, helping the logistics industry to achieve leapfrog development.

Keywords: UAVs, logistics industry, commercial markets.

1. Introduction

In recent years, the rapid development of e-commerce and the Internet economy has brought considerable business pressure to the traditional logistics industry. After experiencing the huge impact of the epidemic, society is calling for contactless logistics, which will further impact the traditional logistics industry. A series of new intelligent transportation platforms represented by logistics UAVs are becoming a research hotspot in the logistics industry. On the basis of UAV, logistics UAVs are equipped with the hardware required for transportation and are intelligently set at the software level [1].

In the commercial industry, the use of UAVs as the main transport carrier to carry out logistics package delivery has attracted attention from all walks of life. Since Meituan- the largest food delivery platform in China joined the track of logistics UAVs, it has been continuously researching and improving the performance of its UAVs to make them more suitable for small-scale cargo delivery in urban areas. Unlike Meituan, ZTO Express-one of the biggest express enterprises in China puts the application scenarios of its own UAVs in remote areas for express delivery, which solves the problem of traditional logistics restricted by complex terrain.

While logistics UAVs are being promoted and applied by various logistics companies, there are still some technical problems to be solved. Including hardware-related automatic obstacle avoidance modules, selection and improvement of battery modules, intelligent algorithms for path planning at the software level, and the waterproofness of UAVs involved in bad weather. Since Google implemented the Project Wing delivery UAV research and development project in August 2012, domestic and foreign companies have carried out research in the field of logistics UAVs [2]. Until now, logistics UAVs have not been able to be widely promoted. Due to the following three development bottlenecks: immature technology, unclear market, and immature regulatory policies. This article expounds on the above topics.

2. The basic theory of logistics UAV

2.1. The hardware structure of UAV

The basic hardware structure that makes up a UAV can be roughly divided into battery power system and flight controller is shown in Figure 1. On this basis, various modules are added according to different design requirements, such as obstacle avoidance module, camera module, robotic arm grasping module, and so on [3].

Fig. 1 UAV's basic hardware structure (Photo/Picture credit: Original)

2.1.1 Battery and Power System of UAV

In the battery and power system, the battery is used as the energy input, and the motor drives the propeller as the power output. In between, the ESC (electronic governor) is used as a medium to convert the DC input of the battery into an AC output of a certain frequency, which is used to control the rotating speed. In terms of battery selection, the current mainstream battery types used in UAVs mainly include nickel-metal hydride batteries, steel-cased cylindrical lithium-ion batteries, polymer lithium batteries, and lithium iron phosphate batteries (steel case, aluminum case or soft pack). Most of the batteries used by UAVs are soft-pack lithium polymer batteries. This type of battery is light in weight, high in energy density, large in capacity, and supports high-current discharge.

The ESC and the motor are generally used together as the power output module of UAV. The brush ESC corresponds to the brush motor, and the brushless ESC corresponds to the brushless motor. The brush motor unit has fast response speed, large starting torque, almost no vibration from zero to maximum speed, and can drive a larger load when starting. The disadvantage is that the service life is relatively low due to internal wear. The control of brushless motors is more complicated, requiring more precise control algorithms and high-precision sensor information input, but it can maintain a higher speed. Since the brushes are removed, the most direct change is that there is no electric current generated when the brushed motor is running. Sparks greatly increase the service life, reduce the noise during operation, and run more stable than brushed motors.

2.1.2 UAV's flight controller

The flight controller is the brain of a UAV. A good flight controller can enable the UAV to hover precisely, stabilize the flight attitude, and update flight data in real time. Based on the above, the flight control of logistics UAVs generally has the function of autonomously sensing surrounding obstacles to avoid obstacles, and autonomously planning the best flight route to navigate to the destination.

The flight controller can be generally divided into open-source flight controllers and closed-source commercial flight controllers according to whether it is open-source or not. Representatives of open-source flight controllers include APM, AutoQuad, PX4/Pixhawk, etc. The commercial flight controller mainly includes DJI's A3 series, ZEROTECH X4-V2 UAV flight controller, XAG SUPERX2, and so on [4]. The open-source flight controller can be programmed to modify the function parameters of the flight control, but it cannot be used immediately. Commercial flight controllers are more stable and have mature functions, but they are more expensive and have limited functions that can be adjusted by themselves.

2.2. Transportation process of logistics UAV

According to the different types of transportation tasks, UAV logistics is generally divided into two categories: transportation and distribution [5]. UAV transportation is used for the logistics task of transshipment, while UAV transportation is applied to the final delivery of items to customers. The application scenarios and tasks of UAV transportation are relatively fixed, and the routes are set according to the preset procedures. The task of a general transport UAV is to take off point-to-point with cargo, fly to a designated location, land and place the cargo. The general object of UAV distribution is small goods (<5kg), and the distribution goods are sent to the airport for UAVs by special personnel. After reloading, the UAV will deliver the goods to the destination distribution station according to the route planned by the background system. When the goods arrive, the user terminal will receive the information and can open the storage cabinet of the delivery station to pick up the goods by scanning the code with the mobile phone.

3. Practical application cases and technical challenges

3.1. Practical Application cases

3.1.1 Meituan

As the largest food delivery platform in China, Meituan has also joined the research and development team of logistics UAVs in recent years. In 2017, Meituan started the research and development of UAV delivery. Until the beginning of 2021, Meituan UAVs completed the order delivery task for real users in Shenzhen for the first time, which marked that Meituan UAV delivery officially joined the track. The time has come to 2022. As of August, Meituan's UAV delivery has launched 11 normalized trial operation routes in Shenzhen, covering more than 10 communities and office buildings, serving nearly 20,000 residents, and completing the real-world-user's orders exceeding 75,000. At the same time, more than 400,000 sorties of flight tests have been completed at test airports in Beijing, Shenzhen and other places, and the total delivery flight time has exceeded 10,000 hours [6].

On July 5, 2023, Meituan UAV released the new fourth-generation model. The research and development of this model lasted more than two years. It is a new multi-rotor model focusing on urban low-altitude logistics distribution scenarios. In addition to conventional upgrades in various performances of the original model, this model has also made important innovations in safety. It is the first in the industry to create a three-level security system of "redundant backup operation-safety forced landing-opening the parachute". According to Meituan's financial report for the second quarter of 2022, under the influence of the epidemic, the demand for home delivery surged, and the number of instant delivery orders increased to 4.1 billion. The addition of UAVs can more comprehensively meet customers' more stringent requirements for delivery, allowing consumers to enjoy a better delivery service experience.

3.1.2 ZTO

Compared with Meituan, ZTO's use of UAVs is mainly focused on terminal distribution and branch transportation. Taking advantage of the characteristics of unmanned aerial vehicles not restricted by terrain, short straight-line distances, flexible scheduling, and high timeliness, it provides delivery services to relatively remote areas with complex terrain. In contrast to manual delivery, which involves traversing challenging terrains, such as mountains and rivers, where roads are difficult to access and there is a scarcity of delivery personnel, resulting in high labor costs. The emergence of UAV delivery is a great benefit to both parties.

Taking the distribution in Yueqing, Zhejiang Province in July 2017 as an example, the route for this test run is from Tiangong 2nd Road, Tiancheng Industrial Park, Yueqing to Yueqing First Economic Development Zone, with a straight-line distance of 14.1 kilometers [7]. If it is handed over to the courier for manual delivery, it will take 50 minutes at the fastest if there is no traffic jam in the whole process, but it will only take 20 minutes if it is delivered by UAV, and the time efficiency will increase by 60%.

In October 2018, ZTO Express obtained airspace approval from relevant regulatory authorities including the military in Shaanxi, and officially started normal operation. The mixed flow UAV - Prometheus 1600A was released, signed a strategic cooperation agreement with Xi'an Aviation Base and Western Airport Group, and reached cooperation on jointly building the air rescue airport network layout in Northwest China. The Prometheus 1600A UAV is the first generation of terminal logistics UAV system developed for express delivery in remote mountainous areas. 2.4 kilowatts fuel generator, using gasoline as fuel and converting the fuel into electricity. In addition, it is equipped with a dual power supply redundant power system, which can provide full load for a maximum of 1.5-hour endurance flight has greatly improved the safe working radius and effectively solved the pain point of the short endurance of the UAV. This type of UAV completed its first cargo flight under severe weather conditions in mountainous areas on December 7, 2018 in Xunyang, Shaanxi, a state-level impoverished county.

3.2. Technical difficulties

3.2.1 Path Planning

Route planning can allow UAVs to avoid collisions and crashes caused by overlapping flight routes to the greatest extent. With the vigorous development of artificial intelligence, route planning is also expected to change from traditional manual setting algorithms to "adaptive" algorithms. At present, the mainstream path planning algorithms include the following four classic algorithms and two new bionic intelligent algorithms: A* algorithm, particle swarm algorithm, ant colony algorithm, genetic algorithm, fruit fly algorithm, and cuttlefish algorithm [8]. How to apply different path planning algorithms in complex airspace based on artificial intelligence algorithms, or even combine multiple algorithms for optimal planning is a major problem in the development of logistics UAVs.

3.2.2 Automatic obstacle avoidance

As the "eyes" of logistics UAVs, automatic obstacle avoidance technology currently has three mainstream solutions: ultrasonic, TOF, and visual image composite technology [].9 Ultrasonic technology and TOF technology both have the disadvantage of being easily disturbed by the external environment, so more and more UAVs are now using visual image composite technology. The visual image composite technology processes the surrounding environment images sent back by the high-definition camera in real-time through a small processor with powerful computing power and achieves a high-precision obstacle avoidance system that can operate stably in a responsible environment [9]. Similar to path planning, integrating and optimizing different obstacle avoidance technologies is one of the difficulties that need to be tackled.

3.2.3 Battery life

As a device that needs to work continuously, the endurance of logistics UAVs has always been a very difficult issue. The larger the battery capacity, the greater the flight endurance, and the larger the size and weight, which will reduce the load capacity of the logistics UAV. Therefore, how to reduce energy consumption and improve energy utilization efficiency to ensure safety is the direction that needs to be vigorously developed at present [7].

3.2.4 Security

Regardless of whether it is a civilian or commercial UAV, the safety of it in bad weather has always been a problem that cannot be avoided. In rainy weather, how can the body structure that cannot be completely enclosed due to the need to maintain internal heat dissipation ensure that the internal circuit components are not short-circuited? A further technical problem is whether the power system of the UAV can execute the preset bottom-level instructions after the flight controller is flooded and short-circuited, so as to land slowly and avoid loss of control caused by incorrect control instructions.

4. Development bottlenecks

4.1. Immature technology

At present, the failure rate of UAVs is still high, and the safety is not as high as that of manual delivery or unmanned delivery vehicles. There are no major breakthroughs in key technologies, and research and development capabilities still require a lot of capital and manpower investment.

4.2. Unclear market

While the demand for home delivery surges, the team of delivery staff is also growing. By the end of 2021, in China, the number of registered real-time logistics delivery personnel will be around 10 million, while the actual number of active logistics personnel will be around 4.5 million. At present, the cost of UAV delivery is still higher than that of human delivery [10]. The cost of technology research and development and the supply chain of UAV-related accessories remains high, and the public prefers human transportation with lower delivery costs. The scope of use of logistics UAVs is limited to the delivery of high timeliness and complex terrain, including some distribution problems in extreme weather, epidemics, etc, and more to make up for the work that delivery staff cannot complete.

4.3. Immature regulatory policies

Civil UAVs collide and crash due to illegal and improper operation, which threatens the personal safety of the people and causes property losses from time to time. As the influence of UAVs continues to expand, regulatory legislation for UAVs is also constantly improving constantly, but most of the documents issued are temporary or urgently revised and issued after a certain event, and there is no uniform standard [11]. Moreover, the current national documents set UAVs under the framework of general aviation management, lacking specific management provisions. The lack of regulatory rules also directly affects the development of logistics UAVs. If the problems faced by logistics UAVs can be solved as soon as possible, the UAV logistics system can enter the market application stage earlier.

5. Conclusion

This paper takes the logistics UAV as the research object and introduces its basic technical principles and specific application cases. It is pointed out that the current technical problems urgently needed to be broken through by logistics UAVs include: path planning, automatic obstacle avoidance, battery life, and safety issues. It further analyzes why logistics UAVs have not been widely promoted at this stage from three aspects: technology, market, and policy. Through the prospect of the rapid development and growth of the Internet of Things, big data, and artificial intelligence. Combined with the continuous development of various related technologies, it is foreseeable that mature logistics UAVs will appear in our field of vision with a new attitude in the near future. At that time, not only major logistics companies will be able to rely on logistics UAVs to improve the industrial structure and greatly improve transportation efficiency, but ordinary people will also benefit from this new logistics model.

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