UAV Autonomous Flight Obstacle Avoidance Technology

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Abstract. With the maturity of drone technology and its increasing application in agriculture, logistics, and even medical fields, the issue of its flight safety in low-altitude complex environments has become increasingly critical. Autonomous flight obstacle avoidance is the core technology to ensure the reliability of drones and the completion of their missions, and it is also the key to breakthroughs in existing technologies. This paper aims to systematically review drone autonomous obstacle avoidance technology. First, from the perspective of "how to make decisions", the drone flight path planning algorithm is deeply analyzed, covering classic global and local planning algorithms as well as cutting-edge machine learning-based methods. Second, from the perspective of "how to see", various sensor technologies used for environmental perception and their applications in ranging and obstacle recognition are sorted out in detail. In addition, this paper also summarizes the software and hardware platforms that carry the algorithms and sensors. This paper systematically reviews drone autonomous obstacle avoidance technology. By deeply analyzing the two core links of path planning and environmental perception, it summarizes the limitations of current technology and looks forward to future directions, providing researchers in related fields with a comprehensive technical map and valuable reference.

Keywords: UAV, obstacle avoidance, path planning, environmental perception.

1 Introduction

With the development of science and technology, drone technology has made significant progress and has been widely used in many fields [1][2][3]. For example, agriculture, military, logistics, medical care, etc. With the diversification of drone operating environments, flight safety has been put on the agenda [4]. In non-fixed environments, for operational safety, the requirements for drone flight obstacle avoidance are extremely high. Autonomous obstacle avoidance not only represents the core technology of drones, but also represents the technological bottleneck that needs to be overcome. Autonomous obstacle avoidance of drones is a highly integrated system engineering technology based on two technical bottlenecks: "How to observe?"--acquire information of obstacle through environmental sensing technology; and "How to decide?"--design safe flying policy through path planning algorithm. The above two

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technical routes constitute the technical scheme of the drone obstacle avoidance technology.

In order to understand the current research status of autonomous obstacle avoidance technology, this article makes a comprehensive introduction to autonomous obstacle avoidance technology of Unmanned Aerial Vehicle (UAV). This article discusses two technical aspects of autonomous obstacle avoidance technology in detail: flight path planning and environmental perception/ranging. In addition, the software and hardware platform that support the above two technologies are also summarized. It is hoped that this research could provide a clear technical roadmap for researchers in related fields and provide them with useful references to promote the further development of autonomous obstacle avoidance technology of UAV.

2 UAV Flight Path Planning.

Drone path planning depends on the starting and destination points of drone and different constraints in the environment of flight, such as terrain obstacles, airspace restrictions and weather.It is a crucial component of autonomous drone flight missions and is crucial for improving drone safety, mission efficiency, and reducing energy consumption. Drone flight path planning algorithms can be broadly categorized into two types: global path planning and local path planning.

According to the flight preparation phase of manned aircraft and various flying objects in the past, before takeoff, an overall path planning is required to conduct a general understanding and pre-assessment of the aircraft's flight path. This is called global path planning [5]. However, global path planning requires a huge database and a high algorithm complexity, but it can usually find the best route. However, in the current global path planning process, two-dimensional static maps, such as Amap and Baidu Map, are often used for rough path planning, which lacks a detailed perception of three-dimensional objects.

Localized path planning can effectively address this problem. It relies on the drone's own sensing system to detect nearby objects or potential hazards and implement real-time obstacle avoidance, offering excellent real-time performance. Furthermore, using its own detection equipment, it can pre-process localized obstacle avoidance information within a small area and return the data to the control console. However, its drawback is also significant: localized obstacle avoidance can alter the overall route, resulting in certain limitations.

Global path planning and local path planning together constitute the general UAV path planning algorithm. The two algorithms complement each other and are indispensable.

For global path planning, the two main algorithms are the A* algorithm and the Rapidly Expanding Random Tree (RRT) algorithm [6]. The A * algorithm is further divided into the iterative deepening A* algorithm, the lifelong planning A * algorithm, and the bidirectional A* algorithm. These A* algorithms are all based on breadth-first search and the Dijkstra algorithm to find the shortest route in the overall route planning. The core of the Rapidly Expanding Random Tree algorithm is random sampling, which is mainly used in high-level space or complex geographical environments to find a usable route. It generates countless random points, like a decision tree in a data structure, and slowly expands into a tree leading to all directions until it finds a route from the current location to the final destination. Li Xinying proposed a new global path planning algorithm. The algorithm combines the improved A* algorithm and the dynamic window algorithm (DWA) to solve the path planning requirements of UAVs in urban environments, to achieve dynamic obstacle avoidance based on the global optimal path. First, the three-dimensional city map is converted into a two-dimensional plane map, and a two-dimensional plane is established using the starting point and target point of the UAV to show the height relationship between the building obstacles and the starting point. This solves the problem of long time and slow calculation speed in the path planning process. Secondly, the Floyd method smooths the global path because the path of the traditional A* algorithm has too many corners, which is not conducive to the flight of the UAV. Finally, the parent node of the smoothed path is extracted. The final experiment shows that the fusion algorithm can provide a smoother and shorter global optimal path in different types of environments. It can also effectively avoid dynamic obstacles in the environment [7].

Local path planning algorithms are mainly divided into three categories. The first category is the artificial potential field method (APF), which controls the flight direction by generating attraction and repulsion around the drone [5]. The second category is the velocity obstacle method (VO), which is mainly used to protect the flight safety of the drone by choosing the appropriate method in the velocity field to avoid obstacles [6]. The third category is deep reinforcement learning (DRL), which adopts the learning method of neural networks and can directly analyze decisions from the original data, providing a new solution for drone visual obstacle avoidance [8]. In actual cases, in order to solve the obstacle avoidance problem of drones in complex environments, a new algorithm combining the artificial potential field method and the ant colony algorithm is proposed. As the ant colony algorithm has little advantage in global planning and slow convergence speed, its search method is optimized, improved heuristic information is introduced, the path node optimization strategy is optimized, and the pheromone update rule is improved. Secondly, the problems of unreachable and local minimum values of the traditional artificial potential field method are solved by adding the relative distance from the mobile robot to the target point into the repulsive potential field function and setting sub-target points. Finally, the path planning performance of the improved algorithm is integrated in complex dynamic and static environments [9].

3 UAV Flight Perception and Ranging

Based on current technologies, drone flight perception falls into two main categories: visual sensors and infrared sensors. Visual sensors can be further categorized into monocular, binocular (stereoscopic), and depth cameras. They work by using the drone's built-in camera to capture images and employ emerging computer vision algorithms to analyze and identify objects posing a threat to the aircraft, transmitting this information back to the central control center. These perception methods have distinct advantages and disadvantages. While they are low-cost and provide a wealth of information, they are also susceptible to weather conditions, require high computational complexity, and require high technical requirements. Infrared sensors, on the other hand, generate images by detecting thermal radiation around the drone and are primarily used at night. This technology is also widely used in the military and medical industries and is more mature.

The main distance measurement methods for drones during flight are laser radar and ultrasonic ranging. Laser radar is a sensor that collects information about the surrounding environment by emitting lasers to generate three-dimensional images. It is a fusion of radar and traditional radar technology in modern technology. Its working principle is to emit a laser beam to the target location and then compare it with the signal received later, such as speed, height, distance, etc. Laser radar is widely used in surveying and mapping, unmanned driving, military and other aspects, which is partly due to its advantages such as small size, strong anti-interference ability and strong detectability [10]. The working principle of an ultrasonic distance sensor is based on the transmission and reception of sound waves. The sensor emits high-frequency sound wave pulses in the target direction. The sound wave is reflected after encountering an obstacle. The sensor calculates the time difference between transmission and reception and the propagation speed of the sound wave in the air to calculate the distance to the obstacle. The effective range of a typical ultrasonic sensor is between 2 cm and 4 m, and the measurement error is usually within 1 cm. Its detection range is small and the angular resolution is low. It is not suitable for the main obstacle avoidance task in high-speed flight and it is suitable for the close-range obstacle avoidance needs of drones in low-speed flight or hovering state.

4 Drone Platform

There are many types of existing drone platforms, but they can be divided into four categories according to their application directions: consumer drone platforms, commercial platforms, examination platforms and open source platforms.

Consumer drones are primarily designed for personal hobbies such as aerial photography and travel documentaries. These platforms demand high portability, ease of use, and resolution to meet user needs. Well-known manufacturers and products include DJI: the Mavic, Mini, and Air series, all of which are recognized as key DJI platforms by consumers. Daotong Intelligent's EVO series drone platform is a strong competitor to DJI in terms of resolution and other performance.

These platforms are different from the consumer drone platforms in that they are required to be much more high reliable and endurance, have much more precise positioning and navigation, and have certain data management ability so that the drone can sustain high endurance in a certain environment, be positioned and navigated with RTK modules in centimeter level and data analyzed precisely.

Now most of the drone testing is on the Lingdong ground station. This software is not a general ground station software, but a software to simplify the way of drawing complicated flight routes. The main user group should be instructors and students in drone training schools.

This software is developed based on the in-house developed flight controller of Lingdong Technology, A7pro. So the software and hardware are platformed together to be more stable. The software is designed in a simple way to plan routes. The drone operators can view and modify the altitude, speed and direction of the flight route. No matter what size of drone or how long distance the flight is and whether it's in VR or not.Those advantages make this software a right choice for the beginner drone operators. Also, this is the designated testing platform for the subjects 3 and 4 of the CAAC drone license exam by the Civilian UAV Aircraft Integrated Management (UOM).

The open-source drone platforms give the enthusiasts and researchers much more customizable space so that they can modify the code freely and meet their requirements. So that the enthusiasts can build their own drone systems or the researchers can do the customized research in any they interested in. The scalability and modularity of the platform give the advantages to easy extend to new sensors and functional modules. Also, the community driven development makes it possible for the enthusiasts around the world to contribute to the development of this platform.

5 Current Situation and Future Prospects

Although the drone path planning technology is constantly developing, there are still many challenges in algorithms, perception, and software hardware coordination. In terms of algorithms, the amount of computational effort and costs are still very high when facing a large number of dynamic obstacles, and there is no guarantee of accurate results. While the newly emerging AI algorithms, deep reinforcement learning, have tremendous potential, they are still insecure due to their “black box” nature and unexplainable decisions, and cannot be widely used in mission-critical scenarios.

At the perception level, the current technology is based on a single sensor, which is difficult to use multiple sources of information, and causes certain deficiencies in robustness and real-time performance of the whole system. Especially in the case of haze, rain, and snow, or in the case of sudden changes in lighting conditions, the performance of the visual sensor and the radar are greatly restricted, and the ability of the drone to fly in all weather conditions is severely limited. The efficiency of the algorithm and the onboard system collaboration is also a key bottleneck. When the drone performs high-speed flight or any complicated motion, the existing algorithms cannot finish real-time calculation and feedback, and the delay of flight control happens, and the flight stability and flight safety are affected.

For these problems, the research in the future will focus on the following directions: First, realize the deep multi-sensor fusion. To realize the high-precision environmental perception in all weather conditions, people need to design more advanced algorithms to make full use of the advantages of different types of sensors. Second, integrate logical determinism of traditional path planning algorithms and powerful logical reasoning of deep learning algorithms well. Through the continuous practice, people can make the two kinds of algorithms complement each other.

In addition, in the future, the path planning system will try to integrate the optimality of global planning and real-time of local planning better to generate efficient and flexible obstacle avoidance routes. At the same time, the road map and the practice of academia and industry on end-to-end reinforcement learning obstacle avoidance methods will continuously deepen. The theoretical research and practice system will be established. Only in this way, can people ensure the performance, safety and reliability of the latest algorithms from simulation to real application.

6 Conclusion

Although there have been many developments in drone path planning technology, there are still many problems in drone path planning technology, algorithms, perception, and hardware/software integration. This article explain the key technologies of autonomous drone avoidance.

This article explain autonomous drone avoidance in two aspects: decision-making and planning, and environmental perception in detail. At the level of decision-making and planning, this article analyzes the evolution from classic global and local algorithms to advanced intelligent algorithms. At the level of environmental perception, the application characteristics of various mainstream sensor technologies in the range and obstacle recognition are explained in detail. In addition, this article also explains the hardware and software platform that supports the implementation of the above technologies.

Through the above summary and analysis of the current technological achievements, this paper hope to provide researchers in related fields with a clear view of the global situation and provide practical references to promote the continuous innovation and development of autonomous drone technology.

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