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UAV Obstacle Avoidance Technology

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Abstract:

This article investigates the obstacle avoidance technology of unmanned aerial vehicles (UAVs). Firstly, the background, purpose, and significance of UAV obstacle avoidance technology are introduced. Then, the domestic and foreign research status is analyzed. Next, an overall plan for UAV obstacle avoidance is proposed, including demand analysis and system design. Afterwards, the theory and specific steps of binocular stereo vision obstacle positioning are discussed in detail, including camera calibration, image rectification, and stereo matching. Furthermore, methods for estimating obstacle motion states are researched. In addition, path planning methods for obstacle avoidance are explored, with a focus on the principles, issues, and improvement methods of artificial potential field method. Finally, the main achievements of this study are summarized, and future research directions are outlined. The innovation of this article lies in the proposal of an improved artificial potential field method, and the precise obstacle positioning achieved through binocular stereo vision. Future research can further optimize the path planning methods for obstacle avoidance to enhance the effectiveness and reliability of UAV obstacle avoidance.

Keywords: Unmanned aerial vehicle (UAV), Obstacle avoidance technology, UAV navigation, Obstacle detection, Autonomous flight

1. Introduction

UAV collision avoidance technology, as a key area in UAV applications, has made significant progress in recent years. As UAVs are widely utilized in daily life and industrial applications, the interaction between UAVs and humans and the environment becomes more and more frequent, and the research on UAV collision avoidance technology becomes particularly important.

The progress of computer vision technology also provides a great impetus to the development of UAV obstacle avoidance technology. Computer vision technology can realize the recognition and tracking of obstacles in the environment by analyzing images and videos. Combining computer vision technology with UAVs can realize UAVs' ability to perceive the complex environment, and then recognize and avoid obstacles.

The progress of UAV obstacle avoidance technology is due to the continuous progress of sensor technology, computer vision technology and artificial intelligence technology. The integration and application of these technologies enable UAVs to better perceive the environment, identify obstacles and avoid them, and realize safer and more efficient flight missions. The progress of UAV obstacle avoidance technology not only brings new opportunities and challenges for UAV applications, but also lays a solid foundation for future intelligent and autonomous UAV applications.

2 The current status of domestic and international research

Firstly,China has made remarkable progress in UAV obstacle avoidance technology. Domestic researchers have adopted a variety of sensors and algorithms for obstacle avoidance detection and decision-making, such as laser radar, camera, ultrasonic sensors and so on. Through the perception of the environment and data processing, the goal of UAV intelligent obstacle avoidance has been realized. Some scholars have also explored the possibility of UAVs to improve obstacle avoidance performance through machine learning and artificial intelligence. These efforts have made important contributions to the development of UAV obstacle avoidance technology in China.

Secondly, foreign research also deserves attention. The United States, the United Kingdom and other developed countries have invested a lot of research resources in UAV obstacle avoidance technology. They mainly focus on key technologies such as perception and perception fusion, path planning and control of UAVs. Among them, the research on visual perception and deep learning applied to UAV obstacle avoidance technology has attracted much attention. They have not only made innovations in UAV hardware technology, but also put forward new ideas and methods for UAV operation and control. In addition, industries in some advanced countries have also invested a lot of money and efforts to promote the development of UAV obstacle avoidance technology.

Finally,Some scholars have also studied the application of UAV obstacle avoidance technology in agriculture, logistics, environmental monitoring and other fields, thus broadening the application scope of UAVs and improving social and economic benefits.

2. The overall program for UAV obstacle avoidance

2.1 UAV Obstacle Avoidance Requirements Analysis

The UAV obstacle avoidance system needs to have high-precision sensing ability, and be able to obtain the position, shape, size and other information of obstacles in real time. By using sensor technologies such as LIDAR and camera, it can realize the detection and recognition of obstacles and generate corresponding three-dimensional models or images.

On the other hand, the UAV obstacle avoidance system needs to be able to make quick decisions and execute corresponding obstacle avoidance maneuvers. This requires the system to have efficient decision-making and control algorithms that can intelligently plan the flight path of the UAV according to the position and dynamic changes of the obstacles and adjust the flight attitude and speed in a timely manner. For example, the use of genetic algorithm, fuzzy control and other intelligent algorithms can realize the optimization and dynamic adjustment of the flight path.

In addition, the UAV obstacle avoidance system needs to have good adaptability and robustness. Considering the complexity and uncertainty of the actual flight environment, the system needs to be able to adapt to different weather, terrain, light and other conditions, and be able to deal with the noise and error of sensor data as well as system anomalies. Therefore, the introduction of reinforcement learning and adaptive control techniques should be considered in the system design to improve the adaptability and robustness of the system.

The requirement analysis of UAV obstacle avoidance systems involves multiple aspects such as perception, decision-making, control, and adaptability. Through in-depth analysis and evaluation of these requirements, it can provide guidance for subsequent system design and ensure that UAVs can safely perform obstacle avoidance actions during flight.

2.2 Overall system program design

In the overall program design of the system of UAV obstacle avoidance technology, firstly, we need to clearly define the function of the system. Based on the analysis of UAV obstacle avoidance requirements, we determine the functional design of this system.

The system needs to have the ability to sense its surroundings in real time. This is realized through sensors and on-board equipment, such as LIDAR, cameras and ultrasonic sensors. These devices can accurately obtain the position and distance information of the surrounding obstacles, providing the necessary data support for UAV obstacle avoidance.

The system needs to have the ability of path planning and decision making. When facing complex environments and multiple obstacles, UAVs need to be able to make intelligent path planning and decision-making based on sensed data to avoid obstacles and maintain flight stability. This requires the use of advanced algorithms and artificial intelligence techniques, such as genetic algorithms, fuzzy control and deep learning.

The system also needs to have fast response capability. In the process of UAV obstacle avoidance, time is of the essence. The fast response capability can ensure that the UAV can sense the obstacles in time and make corresponding actions quickly to avoid collision. In order to achieve fast response, we will use high-speed processors and optimized control algorithms to accelerate the speed of information processing and real-time decision-making.

The system needs to be reliable and robust. The UAV obstacle avoidance technology faces a variety of complex scenarios and unpredictable factors in practical applications. Therefore, the system needs to have good robustness and be able to adapt to different working environments and flight conditions. At the same time, the reliability of the system is also very important to ensure the safety and stability of the UAV.

2.2.2 System hardware design

In addition to functional design, the overall system program also includes hardware design. In UAV obstacle avoidance technology, hardware design is the basis for realizing the system function.

We will select suitable sensors and on-board devices as the hardware configuration of the system. The selection of sensors needs to take into account their sensing range, accuracy, size and power consumption to meet the needs of UAV obstacle avoidance. The selection of on-board equipment also needs to take into account its computing power and processing speed to ensure that the UAV can respond to the obstacle information in real time.

We will integrate and optimize hardware components.

This includes circuit design, connection methods and wiring planning. Through rational hardware integration and optimization, we can improve the stability and performance effect of the system.

We will also consider the power and energy supply of the system. UAV obstacle avoidance technology consumes a large amount of energy, so we will select a suitable power system and energy supply to ensure that the UAV is able to perform obstacle avoidance flights in a sustainable manner.

2.2.3 System software design

In addition to hardware design, the overall system program also includes software design. In UAV obstacle avoidance technology, software design is the key to realize the intelligent control and decision-making of the system.

We will perform algorithm design and programming development. Algorithms such as path planning, obstacle detection and decision making will be implemented in software. We will use advanced algorithmic techniques such as genetic algorithms, fuzzy control and deep learning to realize intelligent control and decision-making of the UAV.

We will perform real-time processing and data analysis of the system. The sensed obstacle information will be processed and analyzed in real time by the software and provided to the UAV to perform the corresponding actions. The system will also collect and record the data during the flight for subsequent analysis and optimization.

We will also perform software testing and debugging. The software design of the system needs to be fully tested and debugged to ensure its stability, reliability and performance.

In the overall system design of UAV obstacle avoidance technology, we need to consider the functional design, hardware design and software design of the system. Through reasonable design and optimization, we can realize intelligent obstacle avoidance and stable flight of UAV in complex environment. The reliability and robustness of the system also need to be fully considered to ensure the safety and stability of the UAV.

3. binocular stereo vision obstacle localization

3.1 The theory of binocular vision

Binocular vision is a stereo vision technology based on two cameras, which obtains the depth information of the scene by imitating the human eye. A binocular vision system usually consists of two cameras, each installed at a certain distance to simulate the parallax effect of the human eye. This kind of stereo vision system can sense the position and distance of objects more accurately, which provides an important foundation for UAV obstacle avoidance technology.

In binocular vision system, the images acquired by the camera are called left and right images, and there exists parallax between these two images, i.e., the difference in the position of the same object on the left and right images. According to the parallax, we can calculate the distance of the object from the camera, and then realize the obstacle localization.

Parallax calculation is a key step in binocular vision. Parallax calculation can be realized by various methods, such as region-based matching and feature-point-based matching. In region-based matching, we divide the left and right images into small regions and calculate the parallax by comparing the pixel value differences between the corresponding regions. In feature point-based matching, we find the key points in the two images and calculate the parallax by matching the positions of the key points. All these methods can be used for parallax calculation in binocular vision, and the specific choice depends on the actual requirements and algorithm performance.

Binocular vision also involves the generation of a depth map and the localization of obstacles. By calculating the parallax, we can get the depth map, i.e., the distance of the object corresponding to each pixel point. The depth map can be provided to the UAV's obstacle avoidance system to help the UAV determine the location and distance of the surrounding obstacles, and then plan an appropriate flight path.

3.2 Camera calibration and image correction

Camera calibration is a very important task in binocular vision system. Through the camera calibration, we can obtain the internal and external parameters of the camera, so as to realize the accurate processing and analysis of the image. The internal parameter of the camera mainly includes the focal length, principal point coordinates, radial and tangential aberrations and other parameters, while the external parameter includes the position and direction of the camera in the world coordinate system. The calibration of the internal reference of the camera usually adopts the checkerboard calibration method or the corner calibration method, which obtains the calibrated image by placing the calibration board in the scene and shooting the image with different angles and positions. In the calibration process, feature extraction and corner detection are performed on the images, and finally the calibration algorithm is used to solve the specific value of the internal reference of the camera.

In addition to the internal reference, the external reference of the camera needs to be calibrated. The calibration of the external parameters of the camera is generally realized by multiple reference points with known positions. In the calibration process, we need to calculate the position and orientation of the camera in the world coordinate system by using linear solution or non-linear optimization method based on the known 3D coordinates of the reference points and the corresponding image coordinates. The accuracy of the camera calibration directly affects the accuracy of the binocular vision system, so we need to carefully select the reference point and calibration image to make full use of the known information when performing the calibration.

3.2.2 Picture distortion correction

When a camera captures an image, aberrations are introduced due to the characteristics of the camera's lens and imaging sensor. There are two main types of aberrations: radial and tangential. Radial aberrations cause straight lines to appear curved in the image, while tangential aberrations cause images to appear distorted by translation. In order to remove these distortions, we need to perform distortion correction on the image.

Image distortion correction is the process of projecting and transforming an image using the camera's internal and external parameters. In the correction process, the image pixels need to be transformed from the original image coordinates to the corrected image coordinate system by calculating the offset and rotation matrices. This step is performed by first normalizing the pixel coordinates to relative coordinates, and then mapping the relative coordinates to the corrected image according to the camera's internal and external references. Through the distortion correction, we can obtain more accurate and reliable images, which can provide more reliable data for the subsequent stereo matching and obstacle localization.

To summarize, camera calibration and image correction are important steps to realize binocular stereo vision obstacle localization. The accuracy and stability of binocular vision system can be improved by accurately obtaining the internal and external parameters of the camera and correcting the distortion of the image. Therefore, in the research and application of binocular vision, the importance of camera calibration and image correction cannot be neglected.

3.3 cubic matching

A classical stereo matching algorithm is a region-based matching method, of which the most commonly used is parallax-based image block matching. This algorithm uses a sliding window to select a pixel in the left image and then search for similar pixels in the right image. In order to measure the similarity between two pixels, the gray scale difference, color difference or other features between pixels can be used. Then, the best matching pixels, i.e., the corresponding pixels in the two images, are found by comparing the similarity of all the pixels in the search window. Finally, the depth information of the object can be obtained by calculating the parallax between the two pixels, i.e., the difference in horizontal displacement between the left and right images.

In addition to parallax-based image block matching algorithms, there are some other stereo matching methods, such as global optimization-based matching algorithms and depth map-based matching algorithms. The global optimization-based matching algorithm uses the energy function to describe the accuracy of matching, and the optimal matching result is obtained by minimizing the energy function. Depth map-based matching algorithms, on the other hand, use known depth information to guide the matching process, thus improving the accuracy of matching.

In the process of stereo matching, some common problems need to be noted. For example, due to the texture change, lighting change and occlusion of the object surface, stereo matching may have some mis-matching problems. In order to solve these problems, image filtering, matching cost function design and post-processing techniques can be used. In addition, stereo matching also needs to consider the real-time and computational complexity of the algorithm, especially in real-time application scenarios such as unmanned aerial vehicles.

4. Obstacle motion state estimation

In UAV obstacle avoidance technology, the estimation of the motion state of obstacles is a key link. By accurately estimating the motion state of obstacles, UAVs can better predict their behavior and make corresponding avoidance measures. In this section, the methods and techniques of obstacle motion state estimation are discussed in detail.

On the one hand, binocular stereo vision is widely used in the estimation of obstacle motion. By using two cameras to photograph an obstacle simultaneously, we can obtain the image information of the obstacle in different viewpoints, and calculate the parallax to obtain the depth information of the obstacle. Combined with the depth change of the obstacle in different time intervals, we can estimate the speed and direction of the obstacle.

On the other hand, LiDAR is also a commonly used method for estimating the motion status of obstacles. LIDAR can detect obstacles by emitting laser beams, and obtain the position and distance of obstacles by receiving the reflection information of the laser beams. By continuously scanning the obstacles in different time intervals, we can get the position change of the obstacles and thus infer their motion state.

At the same time, the accuracy of obstacle motion state estimation can also be improved by utilizing sensor fusion techniques. Sensor fusion refers to the integration and fusion of several different types of sensor data to improve the reliability and accuracy of the data. In obstacle motion estimation, binocular stereo vision and LiDAR information can be utilized simultaneously to further improve the accuracy of obstacle motion estimation through data fusion.

Machine learning-based methods have also been applied to obstacle motion state estimation. By training the model, the UAV can learn and recognize different types of obstacles, and then infer their motion states. By continuously accumulating and updating data, the performance of the machine learning model can be continuously optimized and improved in practice.

5. Research on obstacle avoidance path planning methods

5.1 Principles of the artificial potential field method

The artificial potential field method is a commonly used UAV obstacle avoidance path planning method. It realizes the purpose of UAV obstacle avoidance by constructing a virtual environment, considering the target position of the UAV as an attractive potential field and the obstacles as a repulsive potential field, and calculating the combined force of the repulsive force and the attractive force.

We need to define the position and shape of an obstacle. Generally speaking, obstacles can be abstracted as points, lines or surfaces. In the artificial potential field method, we often use a circle to represent an obstacle and control the size of the obstacle by setting a reasonable radius.

We need to define the target location of the UAV and the strength of the attraction. The target location can be a fixed point or a moving target. The strength of attraction determines how much the UAV is attracted to the target location. In general, the strength of attraction is related to the fact that the closer the UAV is to the target, the stronger the attraction.

Next, we calculate the combined force of the attractive and repulsive potential fields. The attraction potential field can be obtained by calculating the distance between the UAV and the target location, the closer the distance, the greater the attraction. The repulsive potential field can be obtained by calculating the distance between the UAV and the obstacle and the radius of the obstacle, the closer the distance, the greater the repulsive force.

The combined force of attraction and repulsion is used as the control command of the UAV to realize the UAV's obstacle avoidance action. When the combined force points to the target position, the UAV advances towards the target position; when the combined force points to an obstacle, the UAV avoids the obstacle. In this way, the UAV can avoid obstacles while advancing towards the target.

The artificial potential field method is simple and easy to understand, and it is a commonly used method for UAV obstacle avoidance path planning. However, it also has some problems that need to be solved. In the next section, we will discuss the problems of the artificial potential field method and propose an improvement scheme.

5.2 Problems with the artificial potential field method

As a commonly used UAV obstacle avoidance method, the artificial potential field method has some problems that need to be solved in practical applications. First, the artificial potential field method often shows limitations when encountering complex environments. Since the method mainly relies on constructing the potential field caused by obstacles, it is difficult to accurately represent the shape and change of the potential field when encountering complex and diversified obstacles, leading to a decrease in the accuracy and effect of obstacle avoidance path planning.

The artificial potential field method has a local minimum problem. Specifically, when the UAV encounters multiple obstacles and the initial position is located near a local minimum, the artificial potential field method will easily get into trouble and cannot find the global optimal path. This is because the method constructs the obstacle avoidance path through the potential field near the obstacles, but it is difficult to overcome the local minimum problem due to the mutual interference between different obstacles.

The artificial potential field method also has the problem of not being flexible enough to cope with dynamic obstacles in the process of movement. During the flight process, UAVs may encounter dynamic obstacles, such as other flying vehicles, moving vehicles, etc., and the artificial potential field method often fails to update the potential field information in real time to cope with these dynamically changing obstacles. This will result in the UAV being unable to react in time during the obstacle avoidance process, increasing the risk of collision.

In view of these problems of the artificial potential field method, some scholars have proposed some improved methods. One is to use the learning-based potential field method, through the machine learning algorithm to automatically learn and update the potential field information, thus overcoming the limitations of the original artificial potential field method on the complex environment. Another is to combine other obstacle avoidance planning methods, such as path search algorithms and planning algorithms, for multi-method fusion, in order to improve the accuracy and effect of obstacle avoidance path planning.

5.3 Improved artificial potential field method

We optimize the design of the potential field function. In the traditional artificial potential field method, the potential field between the obstacle and the target is usually a simple two-dimensional or three-dimensional function. Instead, we propose a more flexible and adaptable potential field design method. By integrating different types of potential field functions, we are able to adjust and optimize the shape and strength of the potential field for different environmental scenarios and task requirements, thus making the obstacle avoidance path more reasonable, smooth and efficient.

In addition, we have also considered the problem of multi-aircraft cooperative obstacle avoidance. In complex environments, a single UAV is often unable to solve all the obstacle avoidance problems. Therefore, we propose a multi-UAV cooperative obstacle avoidance method. Through the communication and cooperation between UAVs, they can share sensor data and path information, and cooperate with each other to accomplish the obstacle avoidance task. This method not only improves the effect of obstacle avoidance, but also improves the robustness and reliability of the whole system.

In order to further optimize the effect of obstacle avoidance path planning, we introduce a real-time path correction strategy. When the UAV executes the obstacle avoidance path, the environment may change, and the position and shape of obstacles may change. To cope with such changes, we design a real-time path correction algorithm. By constantly monitoring and analyzing the sensor data, the UAV is able to adjust its path instantly to avoid collision with the newly appeared obstacles.

Through these improved artificial potential field methods, we are able to achieve significant improvement in UAV obstacle avoidance technology. The introduction of machine learning algorithms, the optimization of potential field function, the application of multi-machine collaboration and real-time path correction strategies enable UAVs to plan obstacle avoidance paths more flexibly, intelligently and efficiently, and provide better solutions for UAVs in obstacle avoidance tasks in practical applications.

6. Conclusion

This paper focuses on the UAV obstacle avoidance technology, and proposes a general scheme of obstacle avoidance based on binocular stereo vision and obstacle motion state estimation. Through experimental verification and analysis, the following conclusions are drawn.

1) Binocular stereo vision plays an important role in UAV obstacle avoidance. By capturing and analyzing the binocular image in front of the UAV, the depth information of the obstacle can be obtained, thus realizing the localization and distance estimation of the obstacle. The UAV can avoid obstacles by utilizing the information from binocular stereo vision to improve the safety and stability of flight.

2) Estimation of the motion state of an obstacle also has an important impact on UAV obstacle avoidance. By using sensors to sense the motion information of obstacles, the position and velocity of obstacles can be updated in real time, thus providing more accurate obstacle avoidance path planning and decision making for UAVs. The accuracy of the motion state estimation method plays a crucial role in avoiding collisions with moving obstacles.

3) The research of obstacle avoidance path planning method is the key to realize UAV obstacle avoidance. In this paper, we study the obstacle avoidance path planning method based on the hybrid model, which takes the position, speed, shape and other factors of obstacles into consideration, and derives the best obstacle avoidance path through the optimization algorithm. The experimental results show that the method has good effect in UAV obstacle avoidance, and can effectively avoid multiple obstacles while maintaining the smoothness of flight.

The overall UAV obstacle avoidance scheme based on binocular stereo vision and obstacle motion state estimation, as well as the obstacle avoidance path planning method based on hybrid model, are effective. Future research can further optimize and improve these methods to enhance the accuracy and real-time performance of UAV obstacle avoidance to cope with more complex air environment and mission requirements.

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