Research on Obstacle Avoidance Algorithm for Four-rotor UAV

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Abstract. UAV is a kind of aircraft which can be operated remotely, fly independently and carry out different tasks with special equipment on board. With the civilian application of UAV becoming more and more extensive, the application scene is becoming more and more complex. Obstacle avoidance technology has become a difficult problem in widening this field and is also the cornerstone of UAV development on a large scale. As the four-rotor UAV has the advantages of high flexibility, relatively simple control, vertical take-off and landing and low maintenance cost, in this paper, a four-rotor UAV with lidar and binocular vision camera is used to realize the obstacle avoidance function by using the artificial potential field method. The feasibility of the method is verified by simulation.

1. Introduction

UAVs are unmanned aircraft that can be operated remotely, fly independently, perform different tasks with specialized equipment on board and can be reused\cite{1}. In recent decades, with the rapid development of computer technology, artificial intelligence and control theory, the development of high-performance UAV has been widely concerned by many countries\cite{2}\cite{3}.

The development of UAV has a long history. In 1980s, the world's first UAV "Aerial Target" was successfully developed in Britain\cite{4}. After nearly a century of development, UAVs have gradually begun to develop in different industries\cite{5}. They can be found in the fields of remote sensing aerial photography, geological monitoring, aviation plant protection and other civilian areas as well as in military fields, such as low-altitude reconnaissance, counter-terrorism strike, border patrol and so on\cite{6}\cite{7}. Nowadays, UAVs are developing towards chronization, stealth, combat in the air and multi-aircraft cooperation with high altitude and long voyage\cite{8}. Because of its strong maneuverability, strong pertinence, low requirement for take-off and landing environment, low price, the small-sized UAV is being applied in all walks of life, especially as an efficient, safe and cheap way to play a great role in combating crime, military investigation and investigation of cases\cite{9}. How to ensure that the four-rotor aircraft can safely complete the reconnaissance tasks is the key research object in the future. Therefore, it is of great significance to study the automatic obstacle avoidance technology of UAV.

In this paper, PIXHAWK flight control platform with lidar and ZED binocular camera is used as obstacle avoidance system, artificial potential field obstacle avoidance algorithm is used to avoid obstacles through the image of the obstacle distance and azimuth.

2. Structure Frame and Flight Principle of Four-rotor UAV
The four-rotor system consists of four-rotor aircraft and external components. The four-rotor aircraft consists of fuselage body and power system. External components include remote control, earth station, battery and other structures. The remote controls send and receive commands through the receiver of the four rotors. GPS is used to provide position signals, including longitude, latitude and altitude, and to locate.

The four-rotor aircraft is connected by two rigid straight rods of equal length with an angle of 90 degrees. When four motors are fixed at the end of the bar, the four rotor motion can be realized by properly controlling the rotation speed. In general, the reverse torsion moment between the two diagonal motors can be eliminated by the opposite direction of rotation. There are the following types of flight: vertical, pitch, roll, yaw, back and forth, lateral movement, etc.

3. Construction of flight control system
The flight control system is the core of all the systems. It collects and analyzes the attitude and position information from the sensor. After calculation, the command is given according to the instruction. In this paper, the flight control board stm32f429 (PIXHAWK) is proposed. The PX4 flight controller is used as the basic controller for motor output and attitude control. ROS robot operating system is used for task planning, obstacle avoidance and other high-level control. The communication between PX4 and ROS system is solved by using MAVLink protocol, as is shown in Figure 1.

4. Construction of obstacle avoidance module
At present, the development of UAV obstacle avoidance technology presents a multi-development state. As a whole, there are five main kinds of obstacle avoidance technology, that is ultrasonic technology, visual image composite technology, radar technology and electronic map.

In this paper, two schemes are proposed. The first is a kind of obstacle avoidance system with binocular vision. ZED stereo camera is used to obtain three-dimensional images, and accurate obstacle avoidance algorithm is used to realize the accurate perception and avoidance of outdoor obstacles. The second option can carry UTM-30LX lidar. It makes use of TOF technology and Multi-Pulse principle.

5. Obstacle avoidance algorithm
In order to realize the safe autonomous flight of four-rotor aircraft, it is far from enough to rely on obstacle avoidance technology alone. Only by combining obstacle avoidance technology with obstacle avoidance algorithm can we realize safe autonomous flight. At present, the main algorithms of UAV obstacle avoidance include gradient method, spline interpolation method, nonlinear programming method, optimal control method, A * algorithm, neural network method, simulated annealing method, genetic algorithm, ant colony algorithm, dynamic programming algorithm, etc.

In this paper, the artificial potential field method is used for path planning which is proposed by Khatib. The basic idea is to design the motion of UAV in the surrounding environment as an abstract
motion in artificial gravitational field. The target point produces "gravity" to the mobile robot, and the obstacle produces "repulsive force" on the mobile robot. Finally, the motion of the mobile robot is controlled by the resultant force. The path planning using artificial potential field is generally more smooth and safe, with simpler structure and lower computational complexity and is widely applied in the field of path planning. The force analysis of UAV in artificial potential field is shown in Figure 2. The resultant force at every point in the path is equal to the sum of all repulsive and gravitational forces.

$$\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3$$

In order to realize the obstacle avoidance function of UAV, it is necessary to plan the path to make the UAV approach the planned path quickly.

If a four-rotor UAV is regarded as a particle model, then Newton's second law will be satisfied:

$$\mathbf{p} = \mathbf{v}$$  \hspace{1cm} (1)
$$\mathbf{v} = \mathbf{u}$$  \hspace{1cm} (2)

where $$\mathbf{p}$$ represents the current position of the UAV, $$\mathbf{p}_{\text{next}}$$ represents the target route point, $$\mathbf{p}_{\text{last}}$$ represents the previous route point. A local path planner is designed to generate the desired position $$\mathbf{p}_{\text{aim}}$$ in real time. The UAV is then guided to fly along the straight path between $$\mathbf{p}_{\text{last}}$$ and $$\mathbf{p}_{\text{next}}$$ to reach the target point $$\mathbf{p}_{\text{next}}$$, as is shown in Figure 3.

Then the foot point $$\mathbf{p}_{\text{perp}}$$ can be described as:

$$\mathbf{p}_{\text{perp}} = \mathbf{p}_{\text{next}} + (\mathbf{p}_{\text{last}} - \mathbf{p}_{\text{next}}) \frac{(\mathbf{p}_{\text{now}} - \mathbf{p}_{\text{next}})^T (\mathbf{p}_{\text{last}} - \mathbf{p}_{\text{next}})}{||\mathbf{p}_{\text{next}} - \mathbf{p}_{\text{last}}||^2}$$  \hspace{1cm} (3)

$$\mathbf{p}_{\text{now}} - \mathbf{p}_{\text{perp}} = A(\mathbf{p}_{\text{now}} - \mathbf{p}_{\text{next}})$$  \hspace{1cm} (4)

$$A = I_3 - (\mathbf{p}_{\text{last}} - \mathbf{p}_{\text{next}})(\mathbf{p}_{\text{last}} - \mathbf{p}_{\text{next}})^T$$  \hspace{1cm} (5)

Hence:

$$\mathbf{p}_{\text{aim}} = \mathbf{p}_{\text{now}} + k_1(\mathbf{p}_{\text{next}} - \mathbf{p}_{\text{now}}) + k_2(\mathbf{p}_{\text{perp}} - \mathbf{p}_{\text{now}})$$  \hspace{1cm} (6)

After planning path, obstacle avoidance controller can be further designed. $$\mathbf{p}_{\text{now}}$$ represents the current position of UAV, $$\mathbf{p}_{\text{next}}$$ represents the target point. A local path planner is designed to generate the desired position $$\mathbf{p}_{\text{aim}}$$ in real time. To guide the UAV to fly to the target point $$\mathbf{p}_{\text{next}}$$...
and avoid the obstacle with a radius of \( r_0 \in \mathbb{R}_+ \) and whose center of sphere is located at \( \mathbf{p}_{\text{tree}} \in \mathbb{R}^3 \). The model is shown in Figure 4.

First, two hypotheses are proposed:
1. The initial position of UAV meets the formula: 
   \[
   (\mathbf{p}_{\text{now}} - \mathbf{p}_{\text{tree}})^T (\mathbf{p}_{\text{now}} - \mathbf{p}_{\text{tree}}) - r_0^2 > 0; 
   \]
2. The target point \( \mathbf{p}_{\text{next}} \) meets the formula:
   \[
   (\mathbf{p}_{\text{next}} - \mathbf{p}_{\text{tree}})^T (\mathbf{p}_{\text{next}} - \mathbf{p}_{\text{tree}}) - r_0^2 \approx 0. 
   \]

![Figure 4. Obstacle avoidance model.](image1)

Then the control rate is designed as:

\[
\mathbf{p}_{\text{aim}} = \mathbf{p}_{\text{now}} + k_1 (\mathbf{p}_{\text{next}} - \mathbf{p}_{\text{now}}) - k_2 ((\mathbf{p}_{\text{tree}} - \mathbf{p}_{\text{now}})^T (\mathbf{p}_{\text{tree}} - \mathbf{p}_{\text{now}}) - r_0^2)^{-1} (\mathbf{p}_{\text{tree}} - \mathbf{p}_{\text{now}}) 
\]

(7)

6. Simulation

The simulation diagram of the route planning model is shown in Figure 5:

![Figure 5. Route planning model.](image2)

\( \mathbf{p}_{\text{now}} = (0,0) \), \( \mathbf{p}_{\text{last}} = (-20,0) \), \( \mathbf{p}_{\text{next}} = (100,200) \):

When \( k_1 = 1, k_2 = 1 \), the simulation result is shown in Figure 6:

When \( k_1 = 1, k_2 = 10 \), the simulation result is shown in Figure 7:
When $k_1 = 1, k_2 = 25$, the simulation result is shown in Figure 8:

The simulation results show that: the bigger $k_2$ is, the faster the UAV fits the planned path.

The simulation diagram of the obstacle avoidance model is shown in Figure 9:
Figure 9. Obstacle avoidance trajectory planning model.

When $k_1 = 1, k_2 = 50$, the simulation results are shown in Figure 10:

When $k_1 = 1, k_2 = 500$, the simulation results are shown in Figure 11:

According to the simulation results, when $k_1$ is still, the bigger $k_2$ is, the farther the distance from obstacle is and the better the obstacle avoidance effect is.

7. Conclusions

In this paper, a four-rotor UAV is taken as the research object. A flight control system based on lidar and binocular vision camera is built. Through the simulation of obstacle avoidance algorithm of artificial potential field, the effect is basically the same as expected, and it will be applied in the future research to the concrete experiment to verify its feasibility.
References

[1] Y. Chen; H. Zhang; M. Xu. The Coverage Problem in UAV Network: A Survey [C] 5th ICCCNT, 2014.
[2] L. Fu; F. Xie; D. Wang, et al. The Overview for UAV Air-Combat Decision Method [C] Control and Decision Conference (2014 CCDC), 2014.
[3] Tao Yujin, Li Peifeng. Development and key Technologies of UAV system. [J] Aeronautical Manufacturing Technology, 2014, 20: 34-39.
[4] Xu Qiyun, Wang Jie, Hao Wenyuan, et al. Developmental course and trend of foreign unmanned figurehter aircraft. [J]. Navigation missiles, 2016, 3: 28-32.
[5] C. Tetrault, A Short History of Unmanned Aerial Vehicles[J/OL]. UAV Industry News, http://www.draganfly.com/news/2009/03/04/a-short-history-of-unmanned-aerial-vehicles-uavs/.
[6] Moss V, Jones D, Nwaneri S. Analysis of homeland security and economic survey using special missions unmanned aerial vehicle utilities[C]// IEEE International Geoscience and Remote Sensing Symposium. IEEE, 2012: 6154-6157.
[7] Negri S, Quarta T A M. Ground penetrating radar survey for civil-engineering applications: Results from the test site[C]// International Conference on Ground Penetrating Radar. IEEE, 2012: 835-839.
[8] Chun Yu Jiangmin, Zhang Heng. Development status and Prospect of UAV. [J] .Airborne missile, 2005, 3: 23-27.
[9] Song Guanghuang. Design of a police foldable six-rotor aircraft. [J] Science and Technology Horizon, 2014(20): 306-306.