Inspection UAV landing navigation system by fusing UWB information and height Data

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ABSTRACT

When the Unmanned Aerial Vehicle (UAV) is guided by the navigation system that only relies on Ultra Wide Band (UWB), the dynamic error of UAV is too large to avoid the obstacles. Additionally, the navigation system needs eight positioning base stations on ground, which is too expensive to widely use. This paper proposes a navigation system which fuses UWB information and height data in order to reduce the dynamic error and number of positioning stations. First, a height-finding radar is mounted on the UAV to obtain height data; second, a new positioning algorithm by fusing UWB information and height data is designed, and only three UWB ground base stations are needed for positioning. The experimental results show that this navigation system is able to guide the inspection UAV to land precisely at the landing area with a diameter of 60cm, at the same time, compared with the navigation system only by UWB, the average dynamic error is reduced by 10%.

Keywords: UAV, UWB, height, landing navigation system

1. INTRODUCTION

With the rapid development of power system in China, transmission line inspection is facing the problems such as long operation cycle and poor line environment, and the traditional manual inspection is confronting enormous challenges[1]. With the advantages of low cost and easy operation,the Unmanned Aerial Vehicle(UAV) fully autonomous inspection is playing an increasingly important role in the line inspection work of power companies[2]. In order to meet the needs of high-frequency wild inspection, UAVs are required to land at the wild distributed airports accurately and reliably.

Presently the UAV can be guided to land at the wild distributed airports by the Global Positioning System(GPS), image recognition and Ultra Wide Band(UWB). The main problems with the guidance by GPS are that the accuracy of the common GPS module can only reach 2m, and there may be signal interference[3,4]. C.G. Peng[5] Proposed a UAV autonomous landing method based on vision . This method mainly relies on the camera, which is difficult to apply in the absence of light and poor light. Q. L. Tian[6] and B.Y. YANG[7] proposed to apply the UWB to UAV positioning. Experiments show that guiding the UAV by UWB is not restricted by environment or light, but the dynamic error is too large to avoid the obstacles during the landing process. Moreover, there are usually eight UWB ground base stations needed to make the system more reliable, but it also makes the system more complicated and expensive.

In order to reduce the dynamic error and number of positioning base stations in the navigation system only by UWB, this paper proposes a navigation system which fuses UWB information and height data. In addition, experiments are carried out to verify the feasibility of this system.

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2. STUDIES ON NAVIGATION SYSTEM

2.1 General framework

The hardware of the UAV autonomous landing navigation system includes inspection UAV, airborne radar and UWB communication positioning modules, etc. The framework is presented in Figure 1. For this navigation system, there are three parts of its work: positioning data acquisition, flight control and UAV landing.

During the landing process, the three UWB base stations on the ground communicate with the airborne UWB tag through wireless carriers, and the distances between the tag and each base station are measured[8]. The radar is mounted on the UAV through the serial port, from which the height data can be obtained. After the data collected by the flight control, the three-dimensional coordinate of the UAV can be calculated according to the three-base station positioning algorithm. The flight control outputs different PWM signals based on the coordinate information and PID control algorithm to adjust the speed of the motor, so as to realize the normal flight and attitude adjustment of the inspection UAV. And then, the UAV is guided to approach the predetermined position. After gradual adjustment, the UAV finally lands at the distributed airport. The whole process constitutes a complete inspection UAV landing navigation system.

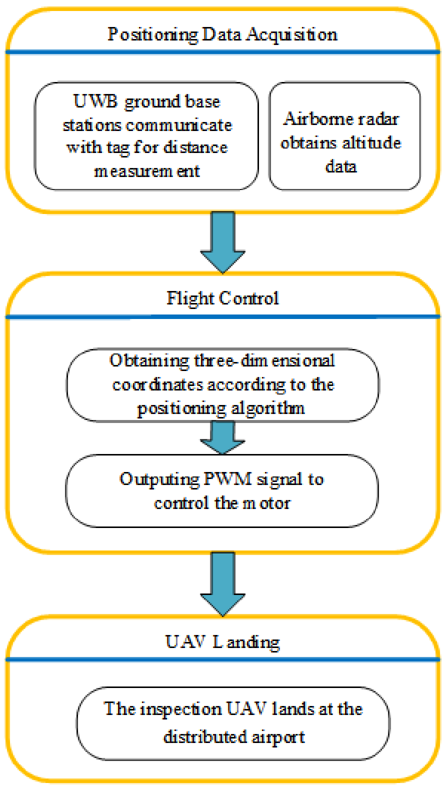


Figure 1. Navigation system framework

2.2 Positioning Algorithm

The traditional UWB positioning algorithm only relies on the distance measurement results of the UWB modules. Due to the error of the distance measurement, it also has a great influence on the positioning result. In order to reduce the error caused by the positioning completely dependent on the UWB, this paper proposes to fuse the UWB information and height data for positioning.

When the positions of the three UWB base stations are known, the distances between the airborne tag and the three base stations can also be known. The three-dimensional coordinate can be calculated by fusing the distance data and the height information of the radar. The schematic diagram of the three-base station positioning algorithm is shown in Figure 2.

A, B, and C respectively represent the locations of the three base stations, and D represents the location of the UAV loaded with the UWB tag. The base station A is placed at the origin, the base station B is placed somewhere on the x-axis, and the base station C is placed somewhere on the y-axis.

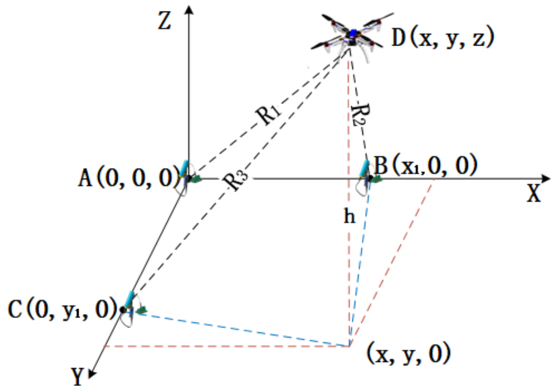


Figure 2. Schematic diagram of three-base station positioning algorithm

If there are two points in the space, the coordinates are (x, y, z) and (a, b, c), and the distance between the two points is R. The relationship between R and the coordinates of these two points can be expressed by formula (1).

$$(x-a)^2+(y-b)^2+(z-c)^2=R^2 \tag{1}$$

Assuming that the coordinate of A is $(0,0,0)$, and the distance between A and the tag is R_1; the coordinate of B is $(x_1,0,0)$, and the distance between B and the tag is R_2; the coordinate of C is $(0, y_1,0)$, and the distance between C and the tag is R_3; the coordinate of the tag to be solved is (x, y, z). According to the formula （1）， there are:

$$\begin{cases} x^2+y^2+z^2=R_1^2 \\ (x-x_1)^2+y^2+z^2=R_2^2 \\ x^2+(y-y_1)^2+z^2=R_3^2 \end{cases} \tag{2}$$

The height measured by radar is h， there is :

$$z=h \tag{3}$$

Solving formula (2) and (3), we can obtain,

$$\begin{cases} x=(R_1^2-R_2^2+x_1^2)/2x_1 \\ y=(R_1^2-R_3^2+y_1^2)/2y_1 \\ z=h \end{cases} \tag{4}$$

3. EXPERIMENTS AND RESULT ANALYSIS

3.1 Experimental Configuration and Process

The experiments were performed with a 30cm diameter, "X"-shaped quadrotor UAV. The radar and UWB tag are mounted on the UAV through the serial port. The layout of the three UWB ground base stations is shown in Figure 3, which is a right-angled triangle with a right-angled side of 600cm.

The experiments are carried out in poor light (Guangzhou, 19:00-20:00). The UAV takes twelve preset position points as the starting points, and all starting heights are 500cm. The landing points for all experiments are $(300cm, 300cm, 0)$. A piece of graph paper with a diameter of 60cm is placed at the landing point, and it is used as the landing area to record the landing errors. After the flight controller receives the landing signal from the upper computer, the UAV adjusts the x-axis and y-axis directions at the same time to land at the landing point safely and accurately.

Figure 3. Layout of UWB ground base stations (unit: cm)

The experimental steps are as follows.

a) Plug in all UWB base stations and place them in corresponding positions. Observe the data to make sure that each base station is working properly.

b) Fly the UAV to the starting point of landing, and after the UAV is stabilized in the air, click on the upper computer to land.

c) The experiment is repeated three times for each starting point, and do a total of 36 landing experiments.

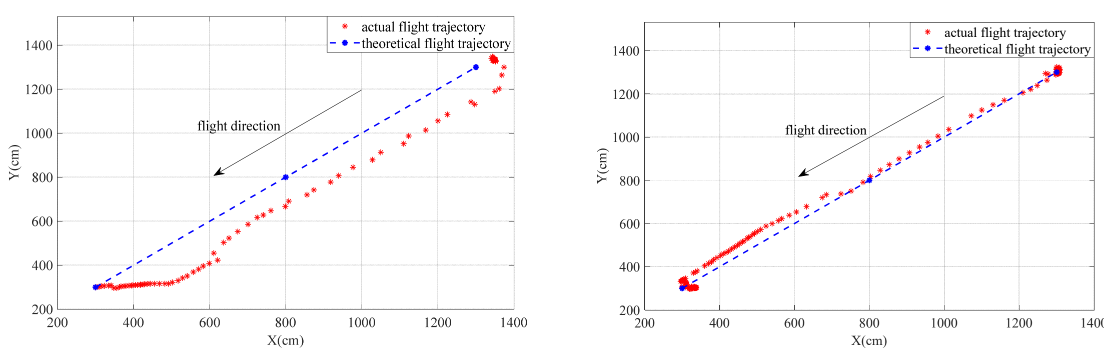
d) Arrange the layout that uses eight UWB ground base stations, and the UAV is guided to land by the navigation system that only relies on UWB. Repeat the above a-c, comparing with this system.

e) Use the GPS and optical flow module to guide the UAV to land respectively, comparing with this system.

3.2 Results and Analysis

3.2.1 Results and Analysis of Dynamic Errors

In order to observe the dynamic errors of the UAV during the landing process, we take the flight experiment with the starting point $(1300cm, 1300cm, 500cm)$ as an example, and record the position data during the landing process. We can get the landing flight trajectory diagrams of the navigation system only relying on UWB and the navigation system in this paper based on the position data. The flight trajectory diagrams of the two navigation systems are shown in Figure 4.



(a) Navigation system only relying on UWB (b) Navigation system in this paper

Figure 4. Landing flight trajectories of two navigation systems

Calculate the dynamic errors according to the formula (5), and the results are shown in Table 1. For the navigation system only relying on UWB, the average dynamic error is 16%, and the maximum is 37%; for the navigation system in this paper, the average dynamic error is 10%, and the maximum is 12%.

$$e_i = \left| \frac{x_i - y_i}{x_i} \right| \times 100\% \tag{5}$$

where x_i and y_i are the x-axis coordinate and the y-axis coordinate of a certain point in the flight trajectory.

Table 1. Dynamic errors of two systems

Navigation system	Average dynamic error	Maximum dynamic error
The navigation system only relying on UWB	16%	37%
The navigation system in this paper	6%	12%

Therefore, compared with the navigation system only relying on UWB, the average dynamic error of the navigation system in this paper is reduced by 10%, and the maximum dynamic error is reduced by 25%.

3.2.2 Results and Analysis of Dynamic Errors

After the UAV has landed on the ground, from a top view, if the UWB tag on the UAV and the origin of the graph paper coincide, the landing error is 0, and the offset between the two is regarded as the landing static error. The results are shown in Table 2. While the optical flow module was used to guide the UAV to land in poor light, the UAV was unable to land and swayed in the air, so the landing error about optical flow module was not counted.

Table 2. Landing static errors of two systems

Navigation system	Average landing static error(cm)	Maximum landing static error(cm)
The navigation system by GPS	219	260
The navigation system in this paper	18	26

Compared with the navigation system by GPS, the average landing Static error of the navigation system in this paper is reduced by 201cm, and the maximum dynamic error is reduced by 234cm.

Count the landing positions of each flight experiment on the graph paper to visually see the distribution of the landing static errors of the navigation system in this paper. It can be seen from Figure 5 that the UAV can land in the landing area with a diameter of 60 cm in each flight experiment.

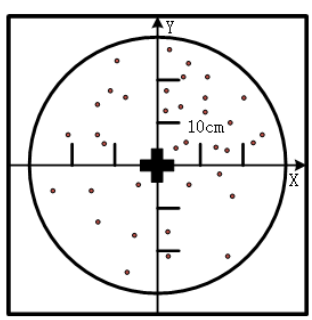


Figure 5. Distribution map of landing static errors of the navigation system in this paper

4. CONCLUSION

Based on the existing UAV navigation system only relying on UWB, this essay has presented a new navigation system, which fuses UWB information and height data. Experiments have also been performed to demonstrated the new navigation system. Two significant findings can be drawn here. The first finding is that the new landing system is capable of applying three UWB base stations to provide landing navigation, while reducing the number of base stations required. The second finding is that the new landing system is able to navigate the inspection UAV to land precisely at the designated destination with a diameter of 60cm, at the same time, the dynamic error is less than 12%. It can be concluded that our new UAV landing navigation system contributes significantly to the UAV fully autonomous inspection.

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