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The altitude hold algorithm of UAV based on Millimeter Wave Radar sensors

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Abstract—**In order to make the unmanned air vehicle(UAV) in the flight process to better complete the altitude control, and can perform more accurate tasks. This paper presents the altitude control based on Millimeter Wave Radar sensors, and combined with the Pixhawk (The flight controller of UAVs) design altitude hold algorithm. The main idea is to transmit the sensor's measurement data to the Pixhawk via the serial port and to fuse with the predictor of the accelerometer. At the same time, the telecontroller switch into Altitude Hold Mode (It is a mode that can make the UAV keep a fixed altitude flight). The UAV will be keeping the target altitude which is set in the program. Finally, compared with the data collected by the Vicon (Motion capture system), to verify the effect of the algorithm. The experimental results show that the Millimeter Wave Radar sensors accuracy meet the demand of subject, and the UAV flight is very stable.**

Keywords-component; Millimeter Wave Radar sensors; Pixhawk; altitude hold algorithm; Vicon

I. INTRODUCTION

Altitude measurement is a very important part of UAV flight, which is one of the key factors that affect the terrain following and terrain matching. It is by measuring the distance between the UAV and the ground, and then guiding the UAV to fly smoothly. The altitude measurement sensors mainly divided into absolute altitude measurement sensors and relative altitude measurement sensors. The absolute altitude measurement sensors is to measure the absolute altitude of UAVs relative to the sea level, generally used for high altitude flight platform, including Barometer [3] and GPS sensors [5]. The relative altitude measurement sensors is to measure the relative altitude of UAVs relative to the Earth's surface, and is generally used in low-altitude flight platforms, including Ultrasonic sensors, Laser Radar sensors [1] and Millimeter Wave Radar sensors [6] [9]. The comparison of mainstream altitude measurement sensors in domestic and abroad is shown in TABLE Ⅰ.

TABLE I. THE COMPARISON OF ALTITUDE MEASUREMENT SENSORS

Sensors	Ranges	Precisions	Advantages	Disadvantages
Barometer	80000m	0.5m	Low cost	Large error
Ultrasonic	5m	0.1m	High accuracy, low cost	Easy interference
Laser	200m	0.02m	High accuracy	Expensive, influenced by environment
Millim-eter wave	50m	0.05m	High accuracy, all weather work	Slightly higher cost

Now the UAV has been used altitude measurement sensors, are generally through the Ultrasonic sensors or Barometer to achieve. The Laser Radar sensors are expensive and vulnerable to environmental impact, so it is not used on UAVs on a large scale. When the Ultrasonic sensors are used single, its scope of measurement is usually not more than 5m, and poor anti-interference ability. It generally as an auxiliary altimeter .Therefore, in the market today, some consumer-class UAVs has been combined with the visual [2] [4], and the effect is good. The Barometer is use the principle of different altitude to produce different air pressure to measure the altitude. In the course of the measurement it has the advantage of being free from obstructions, wide measuring range and easy movement. Though air pressure and temperature to calculate the altitude, it will also bring a greater error. Especially in the near ground measurement, due to the wind, humidity, dust particles and other effects, the measurement accuracy will be greatly affected. Thus, the use of a single barometric will allow the UAV to fluctuate and drift in the flight process. In the outdoor, it often combined with GPS sensors.

According to the above factors, this paper proposes the use of Millimeter Wave Radar sensors for altitude measurement sensors. Compared with other sensors, it has strong robustness, high accuracy, all-weather work etc.

The millimeter wave is a wavelength of 1 to 10 mm electromagnetic wave, it is called millimeter wave. And it is located in the microwave and far infrared wave overlap the wavelength range, which has both the characteristics of the spectrum. Meanwhile, millimeter wave has the following advantages:

- Extremely wide bandwidth. Which can improve the measurement accuracy of distance and speed ,and the ability to analyze the target features;
- Narrow beam. It is conducive to anti-electronic interference, clutter and multipath interference

The Millimeter Wave Radar sensors used in this paper, as show in Figure 1, which is based on a 24GHz millimeter wave. The company website is www.nanoradar.cn. By transmitting a beam of fan micro wave to determine whether there are obstacles below, and the relative altitude of the obstacle and the feedback of radar, it will be returned to guide the UAV flying .The sensors uses the 24GHz ISM band, the precision of 0.05m, and light weight design, which can meet the unmanned flight platform (UAV/UAS) helicopters.

Figure 1. Millimeter Wave Radar

II. THE DESIGN OF ALGORITHM

The whole algorithm is divided into three parts: Data analysis module, Filter module and Altitude hold control module, as show in Figure 2. The Data analysis module mainly analyzes the sensor data which is transmitted to the Pixhawk through the serial port. The Filter module is mainly filtering the data of preliminary analytical to ensure the accuracy. The Altitude hold control module means that the filtered data is transferred to the control program part of the Pixhawk. Furthermore, the telecontroller switch into the Altitude Hold Mode.

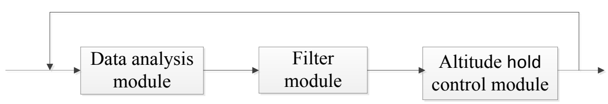

Figure 2. The block diagram of algorithm

A. Data analysis module

The data measured by the Millimeter Wave Radar is sent via the serial port to the Pixhawk for processing. One of its data packets has a total of 14 bytes, each byte of data for the unsigned 8-bit type, the data range of 0 ~ 255 (0 ~ 0xFF). Each data packets has an ID message for distinguishing between different types of messages, as shown in TABLE Ⅱ. When the Message ID is 0X70C, it indicates that the packet is what we need to analyse. Analyze the raw data according to (1), in the (1) the AltitudeHValue is the higher 8bits of the distance, the AltitudeLValue is the lower 8 bits of the distance.

$$Altitude = (AltitudeHValue \times 256 + AltitudeLValue). \quad (1)$$

TABLE II. MESSAGE ID DEFINITION

Number	Message ID	Comment
1	0X200	Sensor Configuration
2	0X400	Sensor back
3	0X60A	Sensor Status
4	0X70B	Target Status
5	0X70C	Target Info

B. Filter module

In this paper, complementary filtering is used as the filtering algorithm, also known as the Mahony filter. It has the advantages of simple calculation and high precision compared with the Kalman filter.

The algorithm is divided into two parts: prediction and correction. The prediction section estimates the estimated altitude value by the accelerometer. And in the correction section, the estimated altitude is combined with the measured of the Millimeter Wave Radar. Finally get the final value. The block diagram of the algorithm is shown in Figure 3.

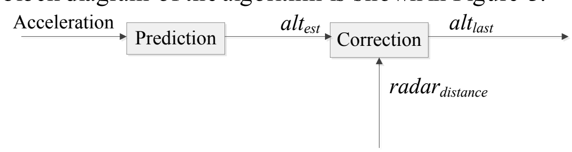

Figure 3. The block diagram of filtering

According to (2) and (3), the altitude estimate of the accelerometer is calculated. Then, the final altitude value alt_{last} is calculated according to (4).

$$alt_{est} = \int vdt + \frac{1}{2}\int vdt. \quad (2)$$

$$v = \int accdt. \quad (3)$$

In (4), $radar_{weight}$ is the given weight, $radar_{coeff}$ is the correction coefficient of radar. According to the subsequent test, the value of $radar_{weight}$ is set to 3.1. And the value of $radar_{coeff}$ is calculated according to (5) and (6). In (5), $radar_{offset}$ is the altitude change of Millimeter Wave Radar, $distance_{ground}$ is the measured value of the Millimeter Wave Radar which is converted to the relative altitude in the body coordinate frame.

$$alt_{last} = alt_{est} + \int (radar_{coeff} \times radar_{weight})dt. \quad (4)$$

$$radar_{coeff} = radar_{offset} - distance_{ground} - alt_{last}. \quad (5)$$

$$radar_{offset} = distance_{ground} + alt_{last}. \quad (6)$$

Since the measured of the Millimeter Wave Radar is for the geographic coordinate frame, in order to allow it to be combined with the Pixhawk accelerometer predictions. On its basis multiplied by the elements which is the orientation cosine matrix R[(2, 2)], see (7). In (7), $radar_{distance}$ is the absolute altitude measured by the Millimeter Wave Radar.

$$distance_{ground} = radar_{distance} \times R[(2,2)]. \quad (7)$$

$$R = \begin{pmatrix} \cos\phi\cos\psi & \sin\theta\sin\phi\cos\psi - \cos\theta\sin\psi & \cos\theta\sin\phi\cos\psi + \sin\theta\sin\psi \\ \cos\phi\sin\psi & \sin\theta\sin\phi\sin\psi + \cos\theta\cos\psi & \cos\theta\sin\phi\sin\psi - \sin\theta\cos\psi \\ -\sin\phi & \sin\theta\cos\phi & \cos\theta\cos\phi \end{pmatrix}$$

In the orientation cosine matrix R, θ is the angle of rotation around the X-axis, ϕ is the angle of rotation around the Y-axis, and ψ is the angle of rotation around the Z-axis.

C. Altitude hold control module

The filtered altitude data will be sent to the Pixhawk local position estimation control program while the telecontroller switch into the Altitude Hold Mode. In the filter module, the acceleration value of the Z-axis accelerometer obtains the speed and height by two integrals. The altitude estimate will be fused with the Millimeter Wave Radar measurement data, which will be used as the outer ring height PID control and the speed and acceleration will be the inner loop PID control. The UAV will keep the target highly flying .The block diagram as show in Figure 4.

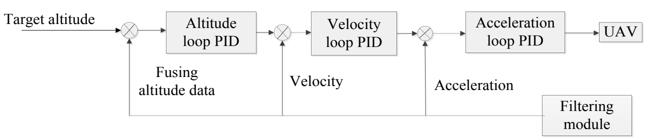

Figure 4. The block diagram of altitude control

III. EXPERIMENTAL

The experimental platform used in this paper is shown in Figure 5. It is completely built independently, mainly using Odroid XU4 (It is a microcomputer that is used for data processing) as the UAV processor, the Pixhawk controller as flight controller. And carry the wireless data transmission module, easy to real-time data transmission to the ground station. Because of the whole flight experiment is in the Vicon. It is necessary to paste the reflective ball on the UAV to ensure that it can be captured by the Vicon.

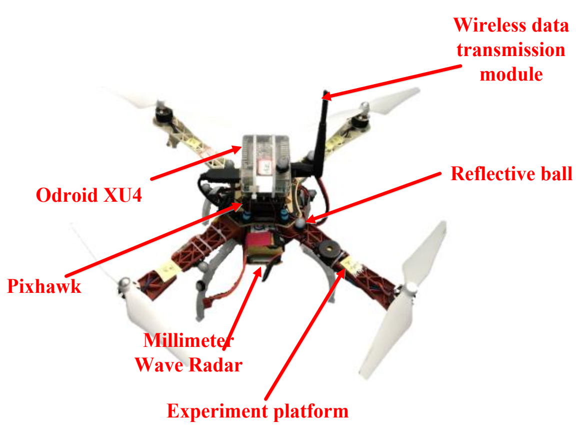

Figure 5. Experiment platform

The Vicon used in the experiment is a high-precision motion capture system [7]. It was developed by the British Oxford Measurement Co., Ltd., which was first used by the British Navy in the 1970s to engage in the research and production of remote sensing, monitoring and control technology equipment. In the 1980s it has been gradually used for medical, sports, engineering, biological and many other aspects of the civil. As shown in Figure 6, the Vicon used in this paper consists of 24 high-speed infrared cameras. It was arranged on the ground and about 2m from the ground, to ensure that the object movement in the coverage area of can be effectively captured.

Figure 6. The system of Vicon

A. Experiment data received

In this experiment, we used 24 high-speed infrared cameras to capture the movement of the UAV. Meanwhile, we use ROS (Robot Operating System) packet which is named Vicon-bridge that is the Vicon official provided, then through the LAN (Local Area Network) to receive the altitude data of Vicon. The Millimeter Wave Radar altitude data through the serial port to the Odroid XU4, and save. As shown in Figure 7, it is the Vicon software interface.

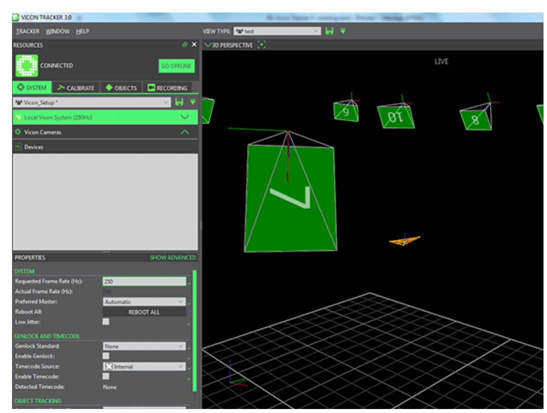

Figure 7. The picture of Vicon software interface

B. Experiment results and analysis

As shown in Figure 8, by comparing the data of the Millimeter Wave Radar with the received data of the Vicon, the following conclusions can be drawn: the Millimeter Wave Radar's altitude hold precision meets the needs of the outdoor experiment; the altitude hold algorithm also achieves the expected effect. In the middle part of Figure 8, it is clear that the UAV hovering around about 1m, and the altitude errors is kept within about 10cm .Due to, the data of the Vicon measurement is based on the distance of the entire UAV centroid to the ground. While the Millimeter Wave Radar installation location is located at 2-3cm below the centroid, so there is a fixed error that we can't eliminate it.

As shown in Fig. 9, it represents that the errors is between the measured value of the Millimeter Wave Radar and the value of current altitude hold. Since the UAV is man-made control before switch into the Altitude Hold Mode, it making the flight altitude in a short time to change greatly. And it also directly leads to the altitude of the middle part of Figure 8 floating up and down.

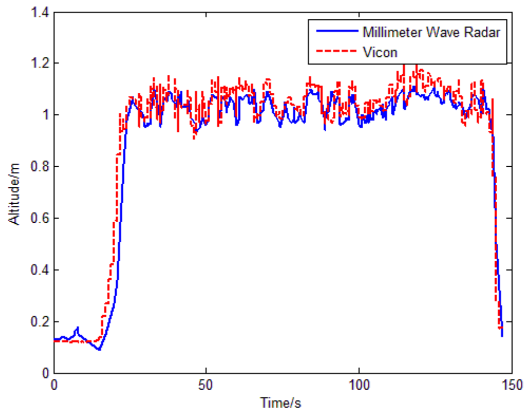

Figure 8. The real-time altitude data comparison during the flight

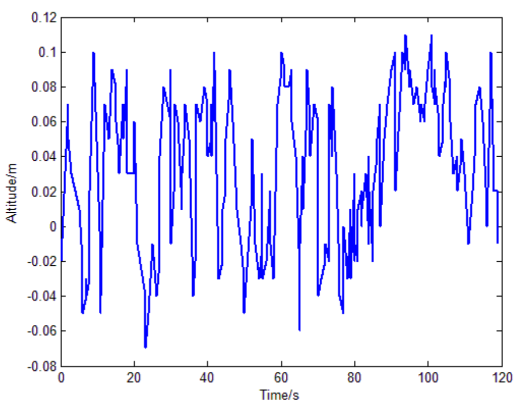

Figure 9. The measurement errors of Millimeter Wave Radar

IV. CONCLUSION

In this paper, the accuracy of the Millimeter Wave Radar and the effect of the altitude hold algorithm are verified by the Vicon. In the course of the experiment, due to the early human operation led to the UAV have errors in the process of altitude hold. However, the filter module can effectively reduce the error at a later stage. For the high accuracy requirements, and require less susceptible to other conditions, the sensor is very necessary. Although it is slightly expensive, making it possible to use only on some professional-class UAVs. With the development of related technologies, it will be used on a large number of UAVs

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