

Research on Reconstruction and Test for Flight Stability of Setting-out UAV

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Abstract. The application of setting-out UAV can enhance automation level of guideline erection operation, simplify erection flow, thus enhancing erection speed of power transmission line, reducing construction cost of erection operation, reliving labor strength of erection workers, and reducing working danger of erection workers. Especially in construction occasions with complicated terrain and severe environment where the artificial erection is difficult to be conducted, complete erection with UAV automatically can enhance construction efficiency greatly [1]. In this thesis, we mainly research the effect of utilizing RTK differential technology to enhancement of flight stability of UAV.

Keywords: UAV, differential GPS, setting-out.

1. Introduction

At present, the single-point positioning precision of satellite navigation system of UAV cannot meet requirements [2]. Due to various inevitable errors, the positioning precision is controlled at the meter level generally, which is not enough to satisfy the requirements for high-precision operation of setting-out UAV. Therefore, to provide more precise positioning service, it is very necessary to improve the traditional UAV positioning and control method.

According to different observed data, the differential navigation can be divided into pseudo-range differential navigation and carrier wave phase differential navigation [3]; wherein, the pseudo-range differential mainly refers to conducting relevant differential calculation by observing pseudo-random code. For the precision of pseudo-random code is relatively poor, the precision of code differential is relatively poor and is mainly used in occasions where the requirements are relatively low. However, the carrier wave phase differential refers to eliminating various errors by utilizing correlation between reference station and mobile station in space; through observing the carrier wave phase value, work out the circumferential ambiguity of carrier wave phase, thus reaching high-precision relative positioning. When the distance is shorter than 20km, the positioning precision can be within 8cm generally.

The real-time kinematic (RTK) differential technology is a kind of differential method which can treat carrier wave phase of measuring station in a real-time way, and this method is a kind of brand-new differential method, and can conduct high-precision navigation and positioning dynamically in a real-time way; in addition, in this thesis, by utilizing RTK differential and combining UAV platform, the setting-out UAV system adopted in erection of power transmission line is developed, and its performance reliability is proved through actual testing.

2. Setting-out UAV system

2.1. Platform design of setting-out UAV

From the perspective of stability of multi-rotor type aircraft, the six-rotor type is better than the four-rotor type. For aircraft, the bigger the amount which participates in the control, the easier the good control effect will be obtained. In addition, if there are relatively many rotors, the tolerance degree of aircraft to effect loss of power system will also rise.

The aircraft platform consists of: aircraft body, aircraft boom and foot stool. The aircraft body adopts carbon fiber and glass fiber reinforced plastics, integrated as a whole, conforming to the carrying strength of large-load equipment. The aircraft boom adopts dismountable mode, convenient for transportation. The foot stool adopts carbon fiber material, which reaches the safety strength when the aircraft is landing. The air power layout of the whole platform adopts six-axis design, which increases safety of aircraft; the wheel base of aircraft platform is 1.6m, which increases the carrying capability and wind resistance of aircraft platform.



Figure 1. Diagram of aircraft real object.

2.2. Hardware of setting-out UAV

The UAV hardware is the carrier of function, and a good hardware platform can make the UAV system own higher precision and more functions; the hardware structure of high-precision UAV platform is as shown in Figure 2:

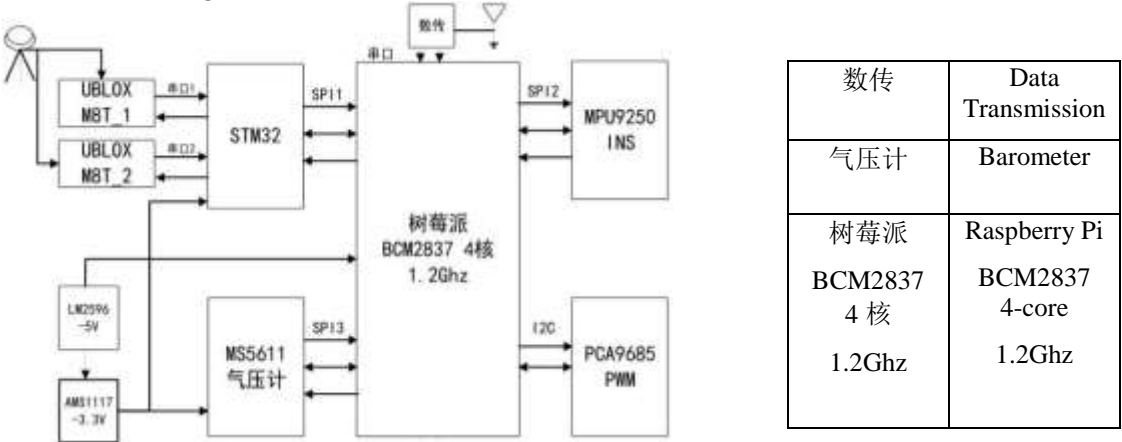


Figure 2. Structural diagram of UAV system hardware.

The UAV system consists of three parts: sensor part, power source part and driving part. The sensor mainly transmits data to CPU via protocol bus; the power source part provides voltage conversion, and the driving part is responsible for driving motor.

2.3. Control program

The control program of setting-out UAV includes control circulation and extended Kalman filter, thus conducting posture and position integration, position posture control, etc. The setting-out UAV conducts automatic control through receiving signals and control commands of various sensors [4], and the detailed software structural diagram is as shown in Figure 3:

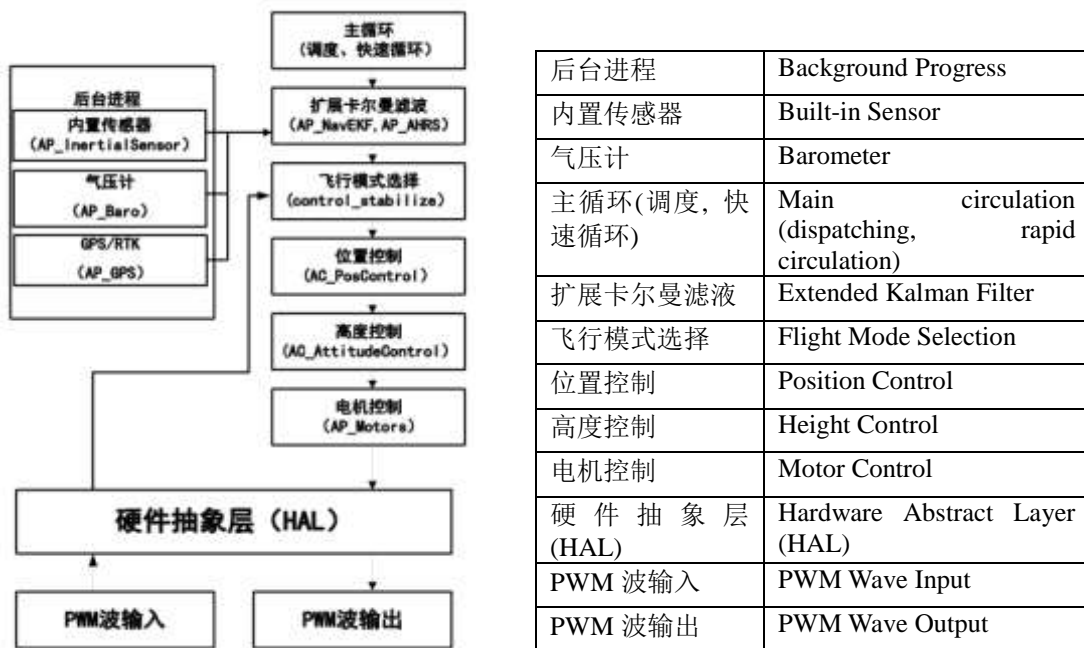


Figure 3. Framework diagram of UAV software.

As a whole, the control program is divided into three parts, i.e. input-control-output; the input refers to remote controller or ground station instructions and sensor data; the control refers to posture control and position control; finally, the control signals are sent to hardware actuator for execution. After compiling this UAV software, we can appoint the data link mode; the software provides multiple modes of data link connection, including serial port, network, SPI, etc.; in addition, it provides multiple channels, and in case that one channel is disconnected, the other channel can be standby to continue the data transmission.

Rtklib is open source differential experimental software abiding by GPL protocol, including various differential algorithms, which are used to provide differential and GPS algorithm researches for scientific research institutions of various colleges; it is featured by strong performance, complete functions, convenient for compiling and running, for it conforms to open source protocol, and can change code conveniently to realize debugging and actual using of algorithm.

The software design mainly involves communication and coordination between Rtklib software and UAV software, and to avoid strong coupling between software, we adopt network protocol for mutual communication between courses, and the navigation data is switched by adopting standard NMEA protocol.

2.4. RTK differential reference station

The differential reference station is the premise of differential navigation. The board card recommended by reference station is Trimble of the USA. For the UAV needs reference station which

can be used portably in the field firstly, the portable differential mobile reference station is as shown in Figure 4:



Figure 4. Mobile base station.

The reference station can send differential power to differential flow station via different communication manners, and the differential flow station hereby is the differential software running on UAV; after the differential software receives the differential calibration information, and through corresponding algorithm, calibrating self differential error, working out high-precision differential position; meanwhile, through the Socket communication between progresses, input the high-precision position into the UAV software, and then the UAV will integrate the high-precision position information with other sensors for automatic control of position loop. The precision indexes are as shown in Table 1 and Table 2:

Table 1. Positioning precision.

| Mode | Positioning Precision | Maximum Output Rate |
|-----------------|--|---------------------|
| Synchronous RTK | Horizontal 1cm+1ppm Vertical 2cm+1ppm | 10Hz |
| Low delay RTK | Horizontal 2cm+1ppm Vertical 3cm+1ppm | 20Hz |

Table 2. Navigation precision.

| Baseline Length | Precision | Maximum Output Rate |
|-----------------|-----------|---------------------|
| 10m | <0.06° | 10Hz |
| 1m | <0.57° | 10Hz |

3. Basic frame of RTK differential navigation combining UAV system

The overall basic frame of UAV differential system is as shown in Figure 5:



Figure 5. Frame diagram of UAV differential system.

The system design includes software and hardware design of reference station, UAV hardware design, UAV software modification and transplant, differential software design and the interface programming of two kinds of software; wherein, the design of reference station adopts single satellite receiving chip, and by combining Raspberry Pi operating system, the reference station is not only portable, but has very powerful performances, and it can serve multiple surrounding mobile stations through TCP protocol. The UAV differential software uses open source software, which modifies the control algorithm and software interface of UAV mainly, and through a series of software and hardware design, the whole UAV differential system is set up finally.

4. Navigation principle of setting-out UAV differential system

The RTK of Trimble is selected for control combination with the UAV control system, and the scheme for enhancing flight stability of UAV system is shown as below: install 2 double-frequency differential GPS antenna at the top of airplane equipment compartment; meanwhile, deploy a set of reference station on the ground, adopt the RTK differential principle to make the UAV system obtain relatively high horizontal/vertical control precision and navigational control precision.

Its basic principle is as below.

The ground differential reference station can receive the position information [5] from GPS satellite, and transmit position information to UAV system through data chain synchronously. When the ground differential reference station and UAV keep positions static at the same time, the airborne equipment will calculate the relative position deviation between airplane and differential station automatically. When the airplane has any motion, for the ground reference station keeps static all the time, the airplane can obtain the change of relative position with ground reference station through calculation, thus eliminating the deviation of GPS system. When there are 2 sets of antenna system on the airplane, the position shift of two sets of antenna relative to reference station can be calculated respectively, thus converting into the change of airplane navigation.

For the GPS system elevation is eliminated, the centimeter level relative position precision can be obtained through positioning with setting-out UAV; 2 differential antenna can be used to work out the high-precision navigational data, which effectively avoids the influence of electromagnetic disturbance on navigation, and is able to enhance stabilization precision of aircraft system obviously.

5. Complete machine testing of UAV differential system

5.1. Static differential performance testing of UAV system

In this thesis, the research on high-precision differential and UAV is conducted, and the differential and UAV control software are compiled. The final purpose is to make the UAV system owns exact position information and conduct stable flight according to this information.

The setting-out UAV is in an open field, conducts testing on the ground in a static way; the nearby trees are relatively short, and there is almost no reflector; the testing environment and the UAV are as shown in Figure 6:



Figure 6. Outdoor Static Testing Diagram.

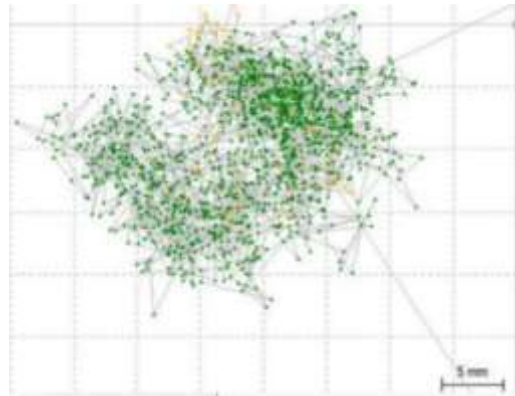


Figure 7. Static Testing Performance Diagram of UAV Differential System in an Open and Wide Environment.

The following refers to testing of such environment, and the result is as shown in Figure 7.

It can be known that the carrier wave phase differential solution [6] can be conducted continuously [6]; in addition, the FIX rate (green spot in the Figure) is very high; in addition, there is micro drifting. FIX (differential high-precision solution)

In an open and wide environment, the combination of micro antenna and portable base station can reach an excellent effect, and the static differential precision is at the millimeter level. From the perspective of principle, once the carrier phase differential is locked and the circumferential ambiguity is worked out, a very high positioning precision can be reached, i.e. within a carrier wave length. Therefore, we utilize this characteristic and have tested an ideal result actually.

5.2. Dynamic differential performance testing of UAV system

Design flight precision test of UAV, adopt RTK differential GPS mode, make the UAV in the status of hovering at fixed point and fixed height, and observe the spatial position drifting situation of airplane within a certain time period in this status; collect the data recorded by flight control computer with flight control ground station. Judge the stability of aircraft system through data analysis, thus further verifying flight stability index of system via test.

5.2.1. *Test steps and contents.* 1. In the weather with wind force below strong breeze (10m/s, the branches start swinging), place the aircraft in the flight site in a static way, open the flight control ground station, energize the control system of aircraft, inspect whether various parameters of the aircraft are normal, and whether the switching of control mode is normal;

2. Hang the counterweight of 5kg, energize the power system of aircraft; after detecting it as normal, control the take off and hovering manually;

3. Control the motion of airplane in six directions, i.e. forward, backward, leftward, rightward, upward and downward, as well as left and right sides of airplane navigation, and inspect whether the flight status of airplane is normal;

4. Control the airplane to the height about 3m away from the ground, and switch to the flight status at fixed point and fixed height;

5. Collect the position data of flight at fixed point and fixed height of airplane within a certain time period, and then analyze the precision of flight at fixed point and fixed height.

5.2.2. Analysis on Test Data. 1. Original Test Data

The original data refers to flight parameters directly downloaded from the flight control computer, through conversion, it generates txt document, and the document records all real-time flight

parameters of the airplane during flight in detail, including time, precision, latitude, flight posture and other relevant data.

2. Data Analysis Method

Through processing original data, remove a part of invalid data which doesn't belong to the fixed point and fixed height flight stage, reserve effective data within the valid time period and then conduct calculation and analysis, thus obtaining calculation result of flight stability at fixed point and forming analysis data.

3. Data Analysis Result

Make statistic of airplane position data via Excel software, and map the change pattern of airplane position in case of flying at the fixed point, as shown in Figure 8 and Figure 9;

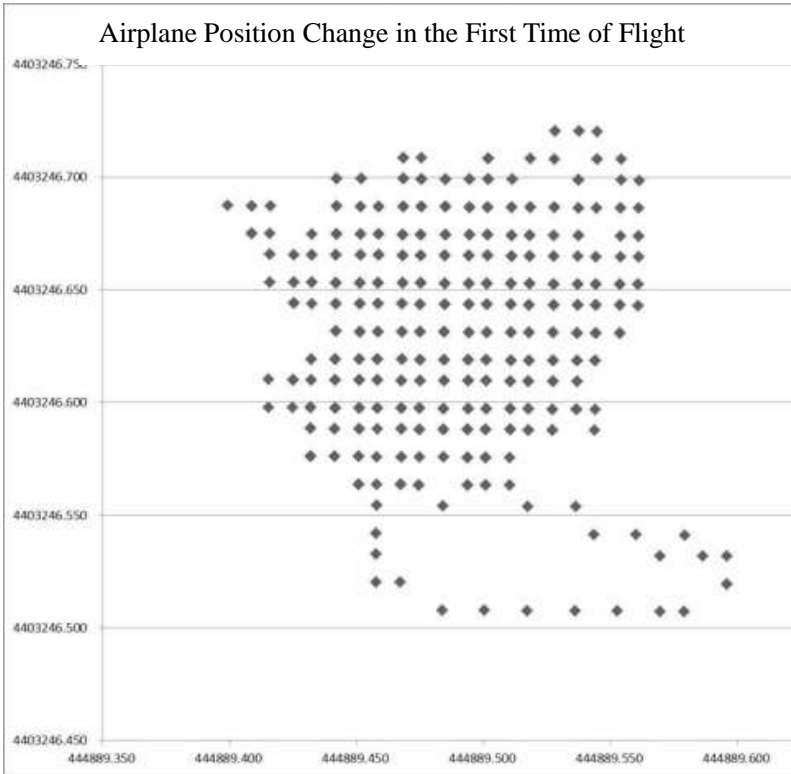


Figure 8. Change diagram of airplane position.

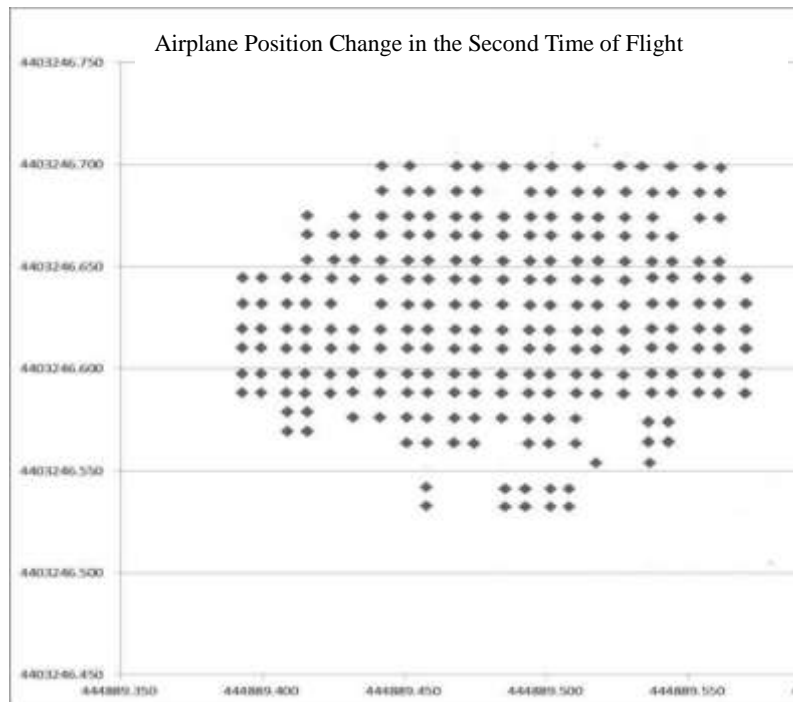


Figure 9. Change diagram of airplane position.

From the result shown by above data, it can be known that the airplane position drifts within the scope of $\pm 100\text{mm}$ transversely and $\pm 100\text{mm}$ longitudinally. Through calculation, the obtained minimum deviation is 0.1mm , and the average deviation is 36.5mm . It can be seen that during actual flight, the positioning error is kept at the centimeter level, and even below the millimeter level.

After conducting classified statistic to error value of each group of data, the error distribution is obtained, as shown in Figure 10:

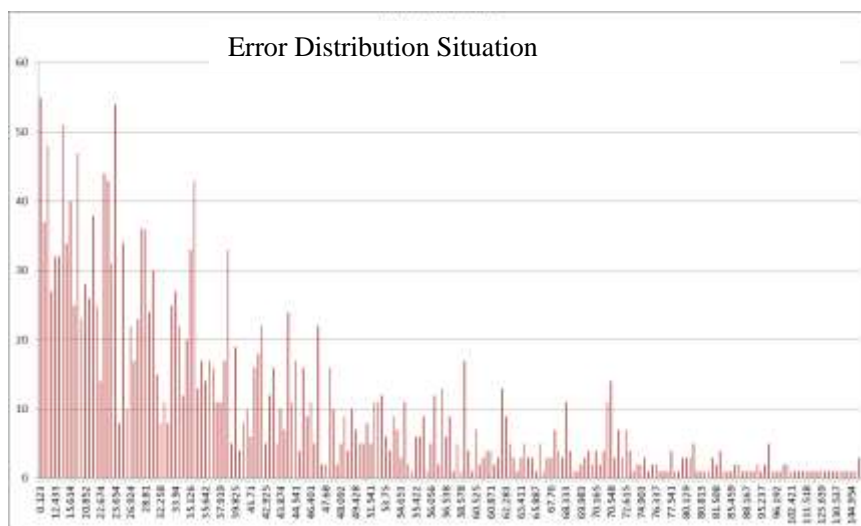


Figure 10. Error distribution diagram.

The horizontal axis in the Figure above refers to drifting value, and the longitudinal axis refers to the number of times of occurrence of such drifting value. From this, it can be known that when the flight is in the flight status at fixed point, the relatively small drifting error of airplane can be controlled possibly, the possibility of occurrence of relatively large drifting error is relatively low, and the control result of fixed point flight of aircraft system tends to the convergence status. By combining

the meteorological factors on the test day for analysis, it is considered that the relatively large deviation is caused by sudden change of wind speed.

6. Test conclusions

6.1. *The scheme of using differential GPS to enhance the flight stability of UAV for setting-out operation is feasible*

The corresponding experimental environment is set up, and under the experimental environment, the experimental verification to enhancement of precision at fixed point and fixed height of RTK differential has been conducted, the functions and performances of UAV differential system under different environments have been tested, and the errors of displacements in various spaces have been analyzed; the static testing proves that the UAV differential system has excellent performances, the dynamic testing shows that the UAV differential system completely meets design demands, and the comprehensive error meets requirements for positioning precision of setting-out UAV, which verifies feasibility of using RTK differential.

6.2. *Able to enhance flight precision at fixed point of aircraft*

After using RTK differential positioning system, within a certain time period, the positioning precision of UAV reaches centimeter level from traditional meter level precision, which effectively enhances the precision of aircraft at fixed point.

6.3. *Meet using requirements in the Project of “the technology of guide rope threading into pulley for launching construction based on trajectory theory shall be researched” [7]*

The constant progress of UAV control technology and differential GPS technology provides technical guarantee for realizing stable flight of setting-out UAV. Targeting the problem that the current positioning precision of UAV is poor, this thesis analyzes necessity of differential GPS to flight stability.

At the stable stage of flight, the positioning precision of double-frequency GPS is within 0.3m, and the precision of dynamic differential positioning is very high, basically reaching the normal theoretical index of RTK differential, and meeting requirements for precision of UAV setting-out completely. This method improves the problem of poor precision of traditional UAV, and verifies key function of differential GPS when the UAV is at fixed point and fixed height.

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