Experimental study on trajectory monitoring of plant protection operation by manned helicopter

Changtong Che[1], Hongze Li[1], Yubin Lan[1,2], Lingjia Kong[3], Dachuan Wang[4], Huilei Xu[5], Hang Zhu[1*]

(1. *School of Mechanical and Aerospace Engineering, Jilin University, Changchun 130022, China*;
2. *College of Agricultural Engineering and Food Science, Shandong University of Technology, Zibo 255049, China*;
3. *Jilin Dingzhi Agricultural Service Co., Ltd, Changchun 130033, China*;
4. *Agricultural Technical Advice Central Station of Jilin Province, Changchun 130021, China*;
5. *Jilin Agricultural Machinery Research Institute, Changchun 130011, China*)

Abstract: With the rapid development of China's agricultural modernization, the efficiency of plant protection operations and the scientific use of pesticides and fertilizers have higher requirements. For crop pest control, agricultural aviation technology has been widely recognized. However, at this stage, manned helicopter aerial plant protection operation is affected by operating conditions, operating environment and pilot experience, which is not enough to ensure the uniformity and stability of the quality of plant protection operation. In order to solve this problem, this paper designs a set of manned helicopter trajectory monitoring system for plant protection operation. With the background of the 2022 summer UCPD agricultural aerial application operation in Jilin Province, a Bell 407 helicopter was used to carry the trajectory monitoring system, and real-time operation data were obtained and statistically analyzed. At the same time, a large number of field trials were conducted to assess the quality of helicopter plant protection operations. The experimental results show that the flight path monitoring system can accurately obtain the flight altitude, speed, operation trajectory, and application trajectory of the aircraft during vegetation operations. The average flight speed of agricultural aerial spraying and plant protection operations in Jilin Province in summer is 140-160 km/h, and the average application efficiency is 65-80 km^2/h. The average flight altitude varies greatly with the operation location. The manned helicopter plant protection operation trajectory monitoring system designed in this article can provide reference for government regulatory departments and farmers to evaluate the quality of aviation plant protection operations, and has practical significance for rational pesticide spraying and promoting precision agriculture.
Keywords: agricultural aviation; plant protection; agricultural spraying; track monitoring
DOI: 10.33440/j.ijpaa.20230601.220

Citation: Che C T, Li H Z, Lan Y B, Kong L J, Wang D C, Xu H L and Zhu H. Experimental study on trajectory monitoring of plant protection operation by manned helicopter. Int J Precis Agric Aviat, 2023; 6(1): 60–67.

1 Introduction

As one of the world's major agricultural countries, China has experienced a significant increase in per capita food availability since the reform and opening-up[1]. However, crop diseases and pests have also become a serious problem. Experts from the National Agricultural Technology Center have analyzed the major trends in crop diseases and pests in China for the year 2022, and it is predicted that significant outbreaks will occur, affecting an area of 2.025 billion mu (approximately 337 million acres) and posing a threat to over 70% of the grain-producing regions[2]. The traditional method of pesticide application, which involves manually operating ground-based equipment, is inefficient, costly, and poses certain risks to the health of workers[3]. In the face of these challenges, modern agricultural aerial spraying has emerged as a new solution[4].

Aerial spraying is a method of applying pesticides, liquid formulations, powders, or granules, evenly over a target area from an aircraft or other flying devices. The advantages of aerial spraying are mainly manifested in three aspects. Firstly, it offers high operational efficiency and strong emergency response capabilities. By utilizing aircraft for spraying, it can effectively alleviate the shortage of agricultural labor caused by the outflow of young people from rural areas. Secondly, it is not limited by crop growth stages, which is beneficial for later-stage operations. Traditional ground-based machinery struggles to operate in the later stages of crop growth, whereas aerial spraying avoids this issue. Thirdly, it allows for timely operations, making the most of the agricultural season. The optimal spraying period for many agricultural products is very short, and only aerial spraying can achieve such high efficiency. Currently, there are three main types of agricultural aircraft: fixed-wing aircraft, manned helicopters, and unmanned drones. Different regions choose suitable flying equipment based on local conditions. In the central part of Jilin Province, which is the Songliao Plain, manned helicopters are highly suitable for crop protection operations. Compared to fixed-wing aircraft, manned helicopters offer advantages such as flexible flight, low requirements for takeoff and landing sites, and high droplet adhesion rates[5].

The United States is currently the most advanced country in agricultural aviation technology, with a history of over a hundred years[6]. Precision aerial spraying technology has significant advantages in terms of efficiency, flexibility, low cost, and safety. In recent years, it has received high attention and promotion from the government and relevant authorities, and has gradually become

Received date: 2023-09-09 **Accepted date:** 2023-12-15
Biographies: Changtong Che, graduate student, Research interests: precision agriculture aviation and equipment. Email: chechangtong98@163.com
***Corresponding author: Hang Zhu**, PhD, Professor, Research interests: precision agriculture aviation and equipment. Telephone number: +86-1808-866-5997, Email: hangzhu@jlu.edu.cn

more well-known[7,8]. However, aerial crop protection operations are mainly carried out by pilots based on requirements and experience, and the quality of flight cannot be effectively guaranteed. Moreover, pilots are employed by the government or other entities, and farmers cannot be sure whether the pilots are conducting operations according to regulations. Therefore, an aerial spraying operation monitoring system needs to be equipped[9].

Aiming at the above problems, this paper comprehensively considers the helicopter flight safety problem and the planting operation trajectory monitoring problem, and designs a set of manned helicopter planting operation trajectory monitoring system based on GPS and BeiDou positioning system. Compared with the monitoring system that comes with the helicopter, this system can not only monitor the flight parameters and drug application of the aircraft in real time, but also record the information of each sortie in detail, and mark the operation track of the aircraft in the flight track. This paper relies on the key research and development program of Jilin Province, and carries out cooperative research and technology promotion and application with Jilin Dingzhi Agricultural Service Co. Ltd, Jilin Agricultural Technology Extension Center, Agricultural Industrialization Department of COFCO Trading Co. Ltd, and Jilin Agricultural Machinery Research Institute, and records a large amount of operation data of the Bell 407 helicopter with the background of applying medication to the fields in the summer of Jilin Province, analyzes the flight speed and the efficiency of the application of the medication, and evaluates the quality of plant protection operations was evaluated to provide a basis for improving the monitoring accuracy of the equipment and the flight situation of plant protection operations.

2 Materials and methods

2.1 GPS positioning principle

The Global Positioning System (GPS) is a satellite-based navigation system that utilizes navigation satellites to provide timing and distance measurements. It is widely used in various fields. The GPS system consists of three components: the space segment, the control segment, and the user segment. The space segment is composed of 24 satellites equipped with atomic clocks. These satellites orbit the Earth and transmit signals that can be received by GPS receivers on the ground. The control segment consists of monitoring stations, master control stations, and ground antennas. The monitoring stations track the satellites and collect data on their orbits and clock accuracy. The master control stations process this data and send it to the satellites for transmission. The ground antennas are used to communicate with the satellites and control their operations. The user segment refers to the GPS receivers that individuals or organizations use to receive and process the signals from the satellites. These receivers calculate their position, velocity, and time by measuring the time it takes for signals from multiple satellites to reach them. Overall, the GPS system enables accurate positioning and navigation by utilizing a network of satellites, ground control stations, and user receivers.

The device equipped with GPS signal receiver is located in the spatial coordinates of X, Y, Z, and the time coordinates of T. The satellite has an internal ephemeris, which allows us to know the exact spatial coordinates of the satellite, X_1, Y_1, Z_1, and there is a precise atomic clock inside the satellite, which also allows us to know the exact time, T_1. The distance S from the device to the satellite is obtained through the time as shown in Equation (1).

$$S = c*(T - T_1) \tag{1}$$

where, c is speed of light, 3×10^8 (m/s).

The distance from the device to the satellite is obtained from space as shown in Equation (2).

$$S = \sqrt{(X - X_1)^2 + (Y - Y_1)^2 + (Z - Z_1)^2} \tag{2}$$

The distances obtained in both ways are the same, and since there are four unknown quantities in the equation, at least four satellites are required to determine the spatial and temporal coordinates of the device. The distribution of four satellites on each of the six orbital planes inclined at 55° with respect to the plane of the Earth's equator ensures that, when observing from any pivot point of the Earth, there are always four or more satellites above the local horizon.

2.2 Monitoring system design

The function of this helicopter plant protection operation monitoring system is to record the flight parameters of the helicopter during plant protection operations, as well as to record the trajectory of the helicopter's application.

The monitoring system is designed based on STM32 microcontroller as well as positioning system. The system uses STM32F030CCT6 microcontroller as the controller, which operates at a speed of up to 48MHz, is inexpensive, and has the simplicity and efficiency of an advanced 32-bit core, as shown in Figure 1.

ATGM336H-5N-31 is selected as the signal receiver module of the positioning system, which is connected to the microcontroller by the USART3 serial port. The chip is highly sensitive, supports both BeiDou and GPS satellite navigation systems, and can realize joint positioning, navigation and timing functions, as shown in Figure 2. The GPS signal is output through the serial port in the NMEA-0183 standard format, based on the ASCII serial communication protocol. This standard communication protocol provides six data formats including GGA, GLL, GSA, GSV, RMC and VTG[10]. When the NMEA statement received by the system via USART3 contains the character ",A,", it indicates that the GPS position is successful and starts parsing the data. In the subsequent statements, the latitude information is obtained by locating the character ",N,", the longitude information is obtained by locating the character ",E,", and similarly the elevation, time and speed information can be obtained, and the obtained speed information is used to judge the working status of the helicopter. Four constants are set as helicopter start speed threshold a=2.5, helicopter start hysteresis threshold a1=10, helicopter stop speed threshold b=0.5, helicopter stop hysteresis threshold b1=20. The helicopter will have two working statuses, resting or working during the whole day's plant protection operation. The default system is at rest before the first planting operation, the acquired speed is compared with the threshold a. If it is greater than the threshold a, the counter is activated to start timing. When the timing is greater than the time threshold a1, the working state is changed from resting to working. Similarly, after two more comparisons with thresholds b and b1, the working state will change from working back to resting, and the system determines that a flight sortie is over.

Selected Hall water flow sensor installed in the nozzle, through the EL357N-G photocoupler connected to the microcontroller, the circuit diagram and the sensor physical diagram shown in Figure 3. When the sensor recognizes that there is a water flow through the sensor will transmit an electrical signal to trigger the counter, after reaching the threshold value, the system will determine the start of the application, and thus to determine the start and end of the work of the spraying system.

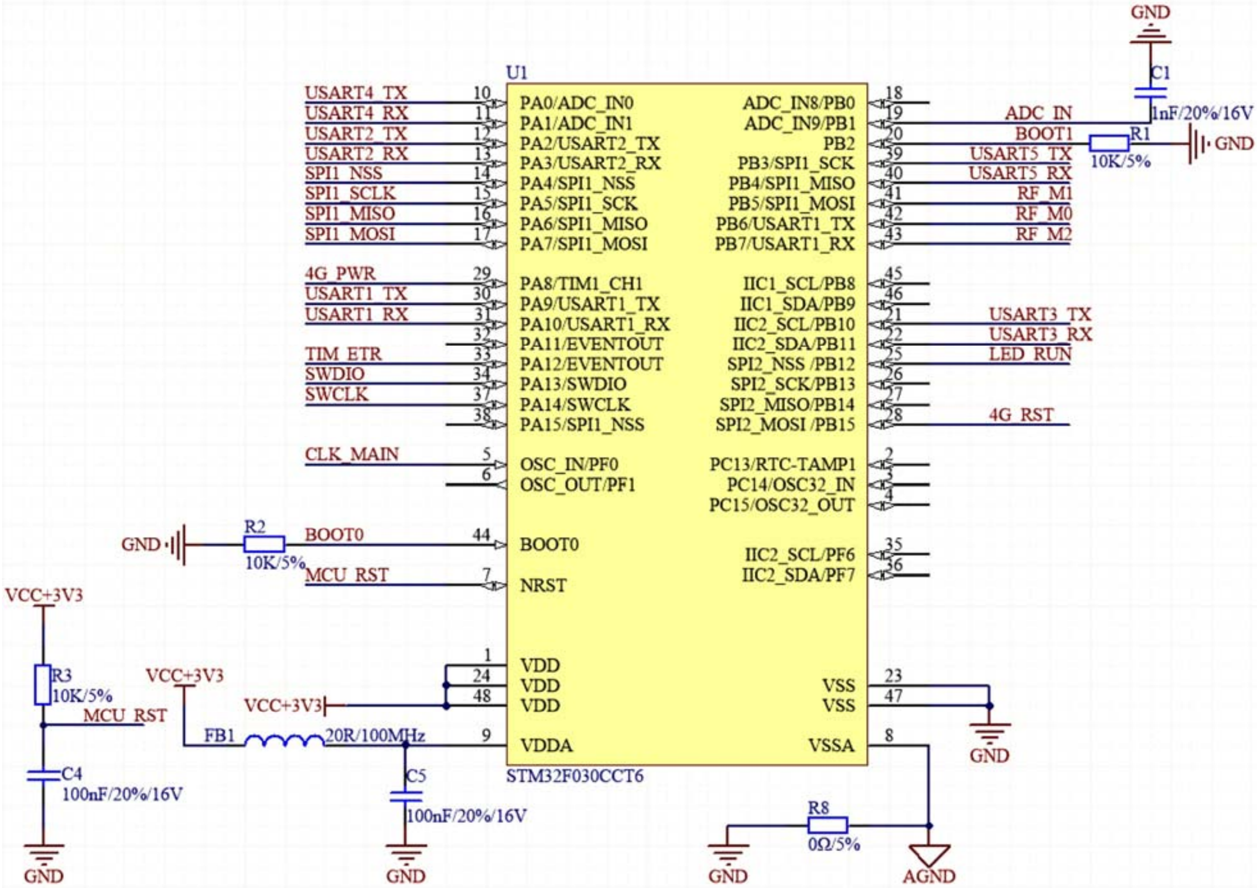


Figure 1 Control module

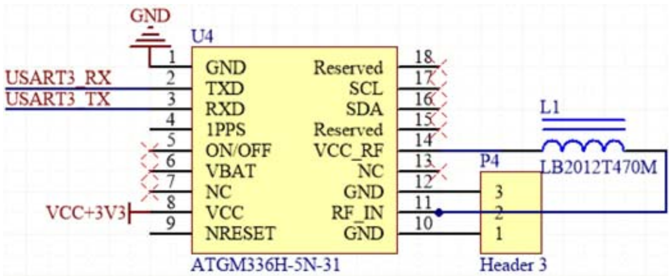


Figure 2 Signal receiver module

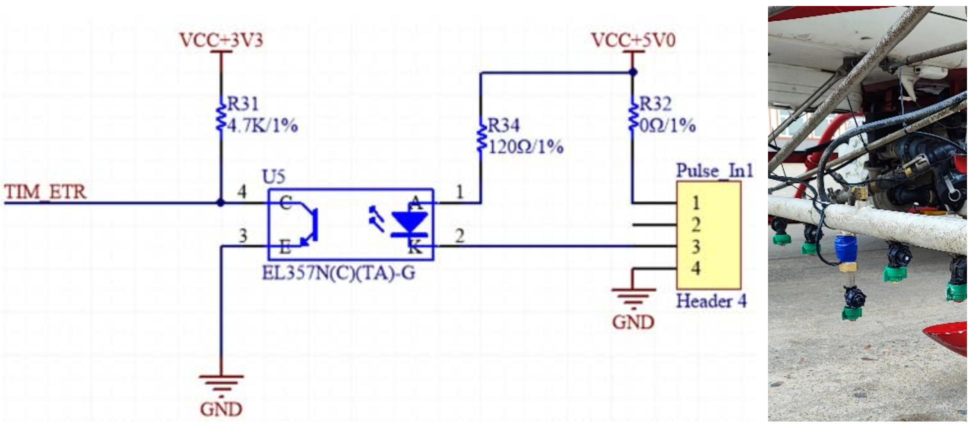


Figure 3 Sensor module

2.3 Experimental design and data acquisition

Jilin Province is an important commodity grain base in China[11]. From the end of June to September, it is the summer field spraying season in Jilin Province. The Bell 407 helicopter is used as the carrier for this monitoring system. The Bell 407 helicopter is shown in Figure 4, and the spray head and boom of the helicopter spraying system are shown in Figure 4a. Figure 4b shows the placement of the monitoring system equipment on the left rear seat of the helicopter. The basic parameters of the Bell 407 helicopter are listed in Table 1, meeting the requirements for agricultural aerial crop spraying operations.

a. Helicopter spray rod b. Monitoring equipment

Figure 4 Helicopter spray rod and Monitoring equipment

Table 1 Bell 407 helicopter parameters

Parameter	Aircraft type
Operation speed/km·h^{-1}	90~170
Working height/m	5~7
Drug loading/kg	800
Length of spray bar/m	8.4
Number of nozzles	51
Nozzle type	Lechler
Spraying system flow/L·min^{-1}	80
Theoretical spray width/m	50

Helicopter plant protection operations begin with the selection of a fixed take-off point according to the area of operation for the day, which is used for re-dosing in the middle of each sortie and for mechanics to repair malfunctions in the helicopter during operations. It was not possible to attach the monitoring system equipment directly to the helicopter, as the helicopter was not allowed to attach any equipment due to safety concerns. Before the first plant protection operation, the monitoring system was placed in the back of the helicopter on the left side of the seat in a stable position and fixed with the seat belt to reduce the vibration of the measurement and improve the accuracy of the measurement. It was observed that the flight was smooth during normal plant protection operations, and there was no sliding of the equipment in the cabin. By the pilot in accordance with the designed route in the prescribed area for plant protection operations, the amount of liquid per mu application according to the local application requirements change, control in about 1 L. Under normal circumstances, the helicopter flies for ten to thirty minutes each time, reasonably planning the operation route and the amount of drug loaded according to the operation area and the distance traveled, and it takes two minutes to refill the drug after landing each time. The monitoring system will automatically send the flight parameters and spraying situation back to the mobile device. Need to pay attention to the flight data sent back from the device, the helicopter flight speed is faster, there is a possibility of signal loss of the device, if you find that the device is only the take-off time without the landing time, it means that the signal is lost, you need to re-open the device at the end of the flight after the aircraft landed. At the same time, the takeoff and landing time of each helicopter operation will be recorded, which will be used to compare the information of the system's recorded sorties and verify the accuracy of the monitoring system.

This year, helicopter crop protection operations have been conducted in multiple locations in Jilin Province, including Dehui City and Songyuan City. The targeted pests and diseases include rice blast, rice stem borer, corn leaf spot, and early maturity promotion in both rice and corn. Corresponding pesticides are sprayed for different targets, and flight aids such as Maifei and Beidatong are added to the pesticide solution. Spray adjuvants can improve the physical properties of the liquid, increase the retention of the pesticide on the leaves by improving surface tension and changing particle size distribution, thus enhancing pesticide utilization. The summary of the participating crop protection operations is shown in Table 2, and the experimental site in Shuangliao City is shown in Figure 5.

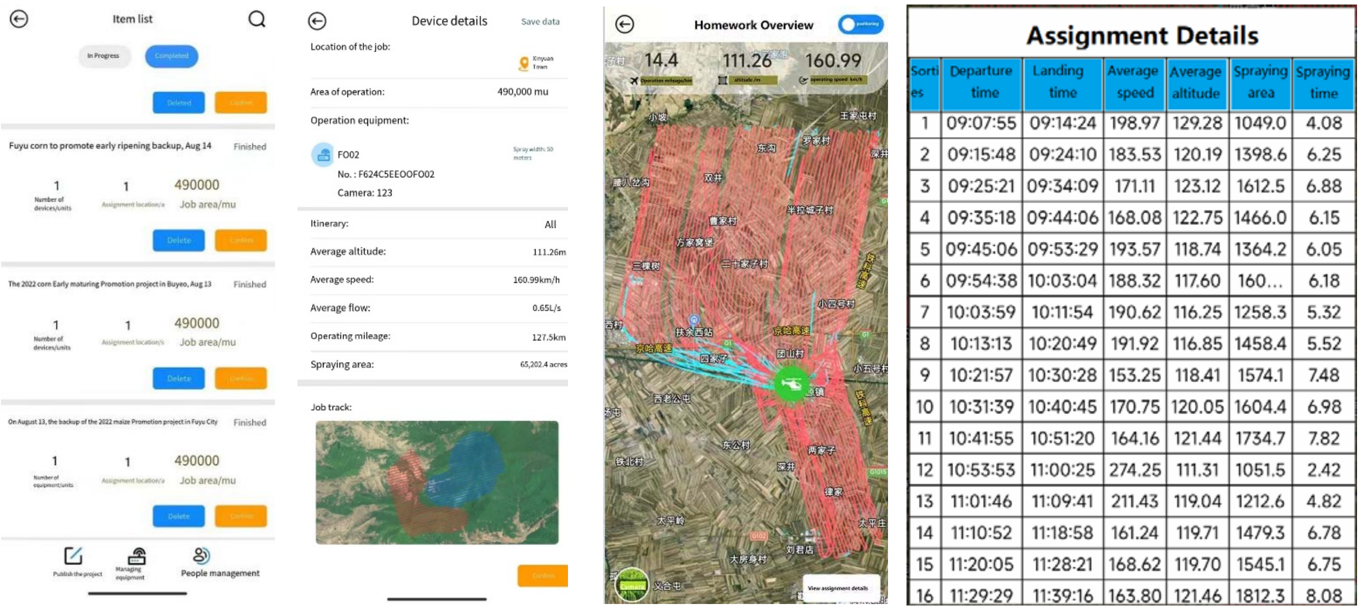
Table 2 Summary of Plant Protection Operations

Place	Working area/mu	Target	Medicament	Flight aid reagent
Dehui	120000	Rice blast	Dao Lifeng	Maifei
Panshi	270000	Rice promotes early ripening	Amino acid containing water-soluble fertilizer	Beidatong
Shuangliao	62000	Rice stem borer	40% chlorpyrifos water dispersible granules (Fuge)	Beidatong
Huinan	335000	Corn promotes early ripening	Amino acid containing water-soluble fertilizer	Beidatong
Liuhe	148000	Corn Leaf Spot and Promoting Early Maturity	Bayer stable and amino acid containing water-soluble fertilizer	Beidatong
Songyuan	120000	Rice stem borer	40% chlorpyrifos water dispersible granules (Fuge)	Beidatong
Fuyu	135000	Rice promotes early ripening	Amino acid containing water-soluble fertilizer	Beidatong
Fuyu	840000	Corn promotes early ripening	Brassinolide	Maifei
Huadian	160000	Corn Leaf Spot and Promoting Early Maturity	Bayer stable and amino acid containing water-soluble fertilizer	Beidatong
Qianan	210000	Corn promotes early ripening	Amino acid containing water-soluble fertilizer	Beidatong
Baicheng	110000	Rice Blast and Promoting Early Maturity	Gufeiyang, water-soluble fertilizer containing amino acids	Beidatong
Baicheng	70000	Rice stem borer	5% chlorpyrifos benzamide	Beidatong

Figure 5 Bell 407 helicopter spraying

2.4 Monitoring system mobile app module

The Monitoring system mobile app module needs to clearly indicate the aircraft's flight status and pesticide application. The record of the August 13th aerial crop protection operation in Fuyu for early maturity promotion in corn is displayed on the mobile interface, as shown in Figure 6. As shown in the project list in Figure 6a, selecting the project name for August 13th allows access to the device details interface, as shown in Figure 6b. In this interface, the total operational area, location, and daily operational area are indicated. From this interface, the daily operational trajectory can be viewed, as shown in Figure 6c. The green airplane icon represents the take-off point for crop protection operations, the flight path is indicated by blue lines, and the red lines represent pesticide application during the flight. Clicking on "View Details" in the bottom right corner of the interface allows for a comprehensive view of the flight parameters for each operational flight of the day, as shown in Figure 6d. The operational details include the flight sequence, take-off time, landing time, average speed, average altitude, spray area, and spray time. The monitoring system interface is clear and concise, and the data is categorized and saved by date for long-term access and inspection by pilots and farmers. This helps reduce disputes caused by unclear aerial crop protection information.



Assignment Details

Sorties	Departure time	Landing time	Average speed	Average altitude	Spraying area	Spraying time
1	09:07:55	09:14:24	198.97	129.28	1049.0	4.08
2	09:15:48	09:24:10	183.53	120.19	1398.6	6.25
3	09:25:21	09:34:09	171.11	123.12	1612.5	6.88
4	09:35:18	09:44:06	168.08	122.75	1466.0	6.15
5	09:45:06	09:53:29	193.57	118.74	1364.2	6.05
6	09:54:38	10:03:04	188.32	117.60	160…	6.18
7	10:03:59	10:11:54	190.62	116.25	1258.3	5.32
8	10:13:13	10:20:49	191.92	116.85	1458.4	5.52
9	10:21:57	10:30:28	153.25	118.41	1574.1	7.48
10	10:31:39	10:40:45	170.75	120.05	1604.4	6.98
11	10:41:55	10:51:20	164.16	121.44	1734.7	7.82
12	10:53:53	11:00:25	274.25	111.31	1051.5	2.42
13	11:01:46	11:09:41	211.43	119.04	1212.6	4.82
14	11:10:52	11:18:58	161.24	119.71	1479.3	6.78
15	11:20:05	11:28:21	168.62	119.70	1545.1	6.75
16	11:29:29	11:39:16	163.80	121.46	1812.3	8.08

a. Project list b. Device details c. Operation track d. Data

Figure 6 Maize plant protection operation in Fuyu City on August 13th

2.5 Verify flight accuracy

Aerial pesticide application is conducted in a complex environment, and the crop protection operation is influenced by factors such as wind speed and temperature. It is difficult to determine the drift of pesticide droplets, making the distribution characteristics of ground deposition an important indicator for assessing the quality of pesticide application and improving the accuracy of monitoring system trajectories [12]. In the experiment, single swath spraying was conducted to observe the deposition and drift of droplets within a single swath by the helicopter. Food-grade lure red dye was added to the spray tank to visually display the droplets on paper cards. During the experiment, two sampling strips with a spacing of 10 meters were set up in the rice field. Each sampling strip had a target area for helicopter flight, and non-target areas were set on both sides of the target area based on wind direction. According to the effective spraying width of the helicopter, the target area in the rice field (or corn field) was set to 50 meters wide with a 5-meter interval between each point, totaling 11 test points. The non-target areas on both sides were 25 meters wide with a 5-meter interval, totaling 5 test points on each side. With this sampling method, each sampling strip had 21 droplet collection points, and the two sampling strips were numbered L1(–10)~L1(10) and L2(–10)~L2(10) respectively. There were 42 collection points in the experimental area. At each sampling point, two layers of Karomiet paper cards (25×76 cm) were placed at the canopy height and bottom height of the rice plants (or middle height of the corn plants) to collect the sprayed droplets[13-14]. Record the temperature and humidity at the time of detection, and measure the wind speed as well as the wind direction using a wind speed and direction meter as shown in Figure 7.

After sampling, the samples were preserved in self-sealing bags and taken back to the laboratory for observation using a computer image analysis system. Data analysis software was used to analyze the droplet coverage density and droplet size distribution [15]. The data obtained can be used to assess the operational quality of the plant protection operation, and the flight trajectory of the helicopter during the plant protection operation can be deduced and compared with the application trajectory plotted by the monitoring system, so as to verify the accuracy of the monitoring system.

Figure 7 Wind speed and direction meter

3 Result and Analysis

3.1 Quality Test Data of Plant Protection Operations in Fuyu City

The examination is scheduled for August 13, 2022, in Fuyu City, Jilin Province. The ambient temperature during the examination will range from 26℃ to 30℃, with humidity levels between 57% and 63%. The wind speed, measured using an anemometer, is expected to be in the range of 1.7 to 2.0 meters per second, and the prevailing wind direction is from the north.

Droplet diameter DV5 with a cumulative distribution of droplets of 50%, i.e. the volume of a grain smaller than this droplet diameter accounts for 50% of the total grain volume, also known as the volume median. Because the droplet size in the deposition region is quite different from that in the drift region, the main deposition region of the droplets is first demarcated when calculating the droplet size. The main deposition region of the droplets is between L1 (–6) and L1 (4) and L2 (–4) and L2 (6), and the droplet volume median diameter DV5 in this region is analyzed to be 201.45 μm and 280.68 μm. Given the spreading of the droplets on the card, the spreading coefficient is about 1.2, and the corrected droplet size is 167.87 μm and 233.90 μm. Therefore, the test results indicate that the droplet volume median diameter is 167.87~233.90 μm, to meet national requirements for aviation low volume spray droplet size (150-300 μm) Requirements for. From the detection results, it can be seen that there is a positive correlation between the droplet diameter and the droplet cover density. the main reason for analysis is that the fine droplets tend to drift off the center of the route, and the vast majority of larger droplets tend to deposit to the center of the route. From the perspective of field aviation operation quality technical indicators, field operation altitude of 5~7 m is suitable, and higher flight altitude will significantly reduce spraying quality, affecting operation quality[16-17].

3.1.1 Fog droplet coverage density

The fog droplet coverage density is the number of fog droplets per unit area, and its calculation formula is shown in Equation (3).

$$X = N / S \tag{3}$$

where, N = Total number of fog droplets; S = total area (cm^2).

The density of fog droplet coverage is shown in Figure 8 and Figure 9. The dashed line represents the flight trajectory of the aircraft, flying along the midpoint of the two sampling bands.

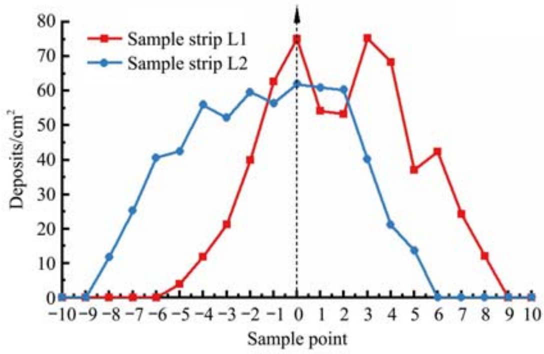


Figure 8 Droplet density coverage in the upper layer of the two sampling belts when the flight altitude is 5~7 meters

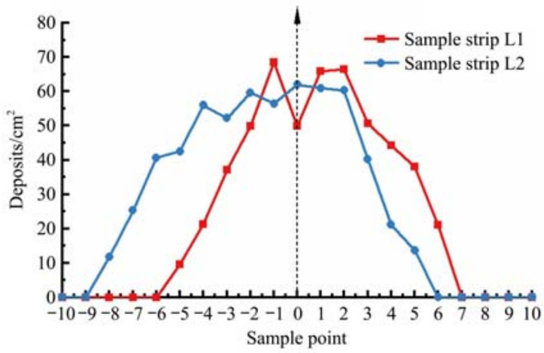


Figure 9 Droplet density coverage in the lower layer of the two sampling belts when the flight altitude is 5~7 meters

According to the quality and technical indicators of agricultural aviation operations, when the aircraft is conducting low capacity spraying of germicide, the droplet coverage density of the operation object is above 15/cm^2 to reach the effective operation spraying amplitude. The pilot flies operations along a planned route, with sample point 0 on the flight path of the monitoring system. Because the wind speed during operation is 1.7~2.0 m/s and the wind direction is north, it will not cause serious drift hazards[18]. As shown in Figure 5 and Figure 6, the sampling points L1(–6) to L1(4) and L2(–4) to L2(6) meet the requirements of the effective operational spray width, the effective operational spray width is 50m, and the fog droplets are deposited more uniformly on the both sides of the flight trajectory, which is judged to be in line with the expectations of the operation. In the case that the fog droplets are not obvious, the line connecting the center of the two sampling bands is the flight path of the plant protection operation, and the flight path displayed on the APP of the monitoring system has the route of the flight and appears red, which indicates that the monitoring system can successfully identify the application of helicopters, and verifies the reliability of the monitoring system..

3.1.2 Distribution of droplet deposition

The amount of droplet deposition is the amount of liquid deposited on a unit area, and its calculation formula is shown in Equation (4).

$$DR = VAD^3 \cdot D_d * 5.23 * 10^{-8} \tag{4}$$

where, DR = Spray sedimentation (L/hm^2); VAD = Average diameter of droplet volume (cm^2); D_d = Droplet coverage density (/cm^2).

The deposition amount of fog droplets is shown in Figures 10 and 11, and the dashed line represents the flight trajectory of the aircraft.

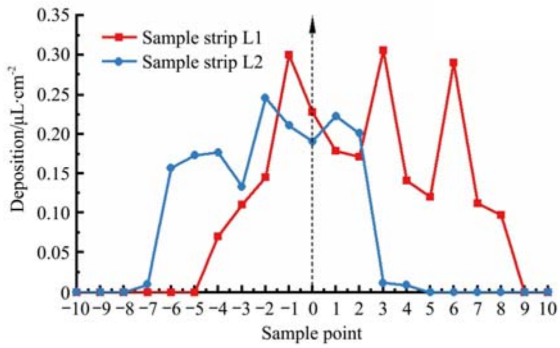


Figure 10 Droplet deposition in the upper layer of the two sampling zones when the flight altitude is 5~7 meters

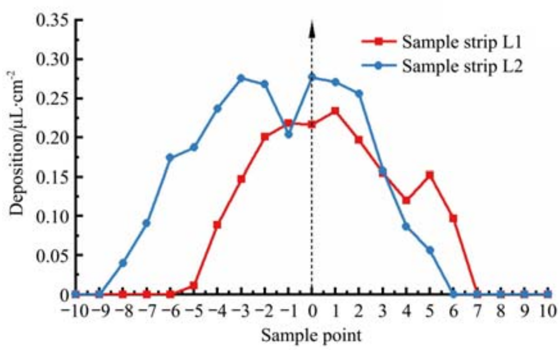


Figure 11 Droplet deposition in the lower layer of the two sampling zones when the flight altitude is 5~7 meters

As can be seen from the test results, the deposition situation is basically consistent with the droplet density. When the flight altitude was 5~7 m, the average values of spray deposition on the upper target crop of the two collection belts were 0.187 μL/cm^2 and 0.158 μL/cm^2, respectively, and the average values of spray deposition on the lower target crop were 0.166 μL/cm^2 and 0.217 μL/cm^2, respectively.

The quality of helicopter aerial operations determined by the Fuyu corn early maturity promotion test on August 13th shows that the quality technology of agricultural aerial operations is affected by a variety of factors. The Bell407 helicopter involved in this agricultural aviation operation, the helicopter itself has a better performance, the spraying operation efficiency is high, for low-volume spraying, the amount of liquid applied per mu is 1.25 L, the density of fog droplet coverage detected in the field is 38~68/cm^2, the density of fog droplets basically meets the requirements. However, the droplet density in the upper layer of the sampling belt as well as the amount of droplet deposition were higher than the value in the lower layer, which also illustrated a drawback of aerial application, i.e., the coverage of the agent in the crop was not uniform, and the middle and lower parts of the crop received less agent.

3.2 Experimental data processing

All of the operational data was organized, and the data from the 25th day of operations, which had a high number of flights, was selected and summarized. In organizing the flight data of the 25th day, it was found that there were still two problems with the monitoring system. One is that occasionally the helicopter shaking in place is wrongly recognized as a helicopter taking off and recorded as a flight of a few seconds at a time, which is recorded as a signal fluctuation. The second is that there will be a situation where there is only the takeoff time but not the landing time, which will be recorded as a loss of signal and will require the equipment to be manually restarted after the helicopter has landed. Comparing the manually recorded helicopter takeoff and landing times with the system-recorded sortie information in several groups, it was found that the data were basically the same, except for the case of signal loss, and it was considered that the accuracy of the sortie information recorded by the monitoring system was high. The errors occurred in the plant protection operation on the 25th are organized as shown in Table 3. In the plant protection operation with a large number of flights, no matter signal fluctuation or signal loss, the error rate is more than 10% is a minority of cases, the accuracy rate is high, and the monitoring results are still trustworthy.

Table 3 Error ratio

Error rate	Signal fluctuation		Signal loss	
	Quantity	Proportion	Quantity	Proportion
0	9	36%	5	20%
0~10%	12	48%	15	60%
10%~100%	4	16%	5	20%

Through the speed of each sortie to find out the average speed of each day of the 25 days is organized as shown in Figure 12. The prescribed speed of Bell 407 is 90~170 km/h. Figure 9 shows that the highest average speed of the 25 operations is the 13th operation, with an average speed of 174.68 km/h, which exceeds the standard maximum value of 170 km/h. The lowest average speed is the 12th operation, with an average speed of 122.71 km/h, which is in line with the requirements of the operation. The average speed of the 25 operations was 96%, basically stabilized at 140~160 km/h.

The 13th application operation was conducted on August 13 in Fuyu City, Jilin Province, to promote early maturity of maize, and as many as 50 flights were conducted on that day, and the average flight speed of each flight was organized as shown in Figure 13. 12 flights were the highest speed, with an average speed of 274.25 km/h; the 42nd flight was the lowest speed, with an average speed of 130.1 km/h. The average speed of all the application operations on that day was 174.68 km/h, with a standard deviation of 27.94, and the specified speed of the Bell 407 application was 90~170 km/h, which means that the actual speed of the Fuyu planting operation was slightly higher than that of the standard. is slightly higher than the standard. From Figure 13, it can be seen that the total area of the prescribed operation on that day was larger, and the operation track was very neat and the single application path was longer in straight line, with fewer turns, which was the reason for the faster flight speed.

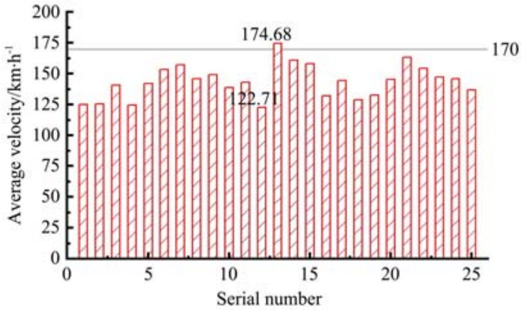


Figure 12 Average velocity

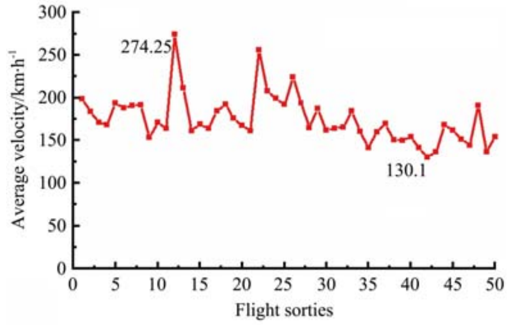


Figure 13 Operating flight speed

From the operation details, we can know the application area and application time of each sortie, and we can find out the average spraying efficiency of 25 application operations per day and organize it as shown in Figure 14, the average daily spraying efficiency is basically in the range of 65~80 km^2/h.

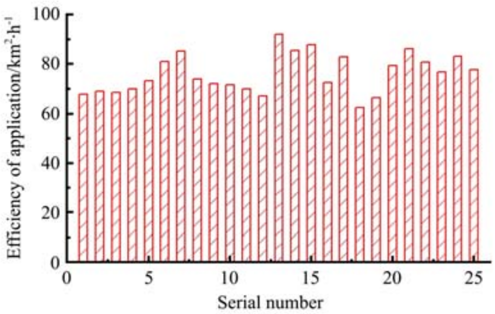


Figure 14 Average spraying efficiency

There are obvious differences in the altitude of helicopter flights during plant protection operations, and the statistical data show that the average altitude difference is large at each operation site. The average flight altitude difference between different flights at the same location is not significant, such as the average flight altitude of 230 m in Huinan County, which is located at the intersection of the Changbai Mountains and the Songliao Plain, 190 m in Huadian County, which is located at the transition front of the Changbai Mountains to the Songliao Plain, and 105 m in

Shuangliao City, which is located in the Songliao Plain. 0.45 L/s, and for corn plant protection operations the average flow rate was about 0.95 L/s.

4 Conclusion

Aiming at the current development situation of agricultural aerial plant protection in Jilin Province, this study designs a helicopter plant protection operation track monitoring system. The three-month test in summer shows that the system can accurately record the flight parameters and drug application of the helicopter, and can draw the flight trajectory and drug application route on the electronic map.

Through the statistical analysis of the complete data of the 25th plant protection operation, the overall accuracy rate is high, and the monitoring system can meet the operational requirements, but there is still the problem of helicopter signal loss or the system incorrectly judges the helicopter takeoff. The next step is planned to independently design a special head for helicopters, and install the monitoring system equipment on the head before the test, which will have the effect of damping the vibration and improving the measurement accuracy. It is planned to solve the problem of signal fluctuation by extending Kalman filtering. At the same time, the problem of fog droplet drift will be considered, and the existing fog droplet drift model will be improved through the ground drug deposition distribution test, which will be combined with the monitoring system to improve the monitoring accuracy of the system and achieve the ultimate goal of efficient plant protection. In the past, there has been no precedent of long-term monitoring of large agricultural aircraft flight data. However, the large amount of monitoring data from this summer provides strong data support for improving plant protection operation flights in the future. As an important part of aerial application, the monitoring system for aerial plant protection operations is gradually attracting the attention of various national R&D departments and promoting the continuous development of precision agriculture in China.

Fund project: Research and Application of Key Technologies for Intelligent Detection of Crop Pests and Diseases in Aerialized Operations, Jilin Province Key R&D Plan Project (20220202034NC)

[References]

[1] Xu Z H, Li C. Current Development and Future Trends in Chinese Agriculture. Agricultural Science and Engineering in China, 2020, 32(06): 3–4. doi: 10.19518/j.cnki.cn11-2531/s.2020.0147.

[2] Huang W J, Liu L Y, Dong Y Y, et al. Research progress of crop pest and disease monitoring based on remote sensing technology. Agricultural Engineering Technology, 2018, 38(09): 39–45. doi: 10.16815/j.cnki.11-5436/s.2018.09.007.

[3] Zhou Z Y, Zang Y, Luo X W, Lan Y B, Xue X Y. Development strategy of technological innovation in China's agricultural aviation plant protection industry. Agricultural Technology and Equipment, 2014(05): 19–25. doi: none.

[4] Zhang D Y, Lan Y B, et al. Progress and Prospects of Agricultural Aerial Application Technology Research in China. Transactions of the Chinese Society for Agricultural Machinery, 2014, 45(10): 53–59. doi: 10.6041/j.issn.1000-1298.2014.10.009.

[5] Liu Y Y, Ru Y, et al. Algorithm for planning full coverage route for helicopter aerial spray. Transactions of the Chinese Society of Agricultural Engineering, 2020, 36(17): 73–80. doi: 10.11975/j.issn.1002-6819.2020.17.009.

[6] Lan Y B. Current status and development trend of precision agriculture aviation technology in the United States. Agricultural Machinery Market, 2022, 408(05): 57–59. doi: none.

[7] Lan Y B. Status and role of precision agriculture aviation in China. Agricultural Machinery Market, 2021(04): 23–24. doi: none.

[8] Lan Y B. Current status and future outlook of precision agriculture aviation technology. Agricultural Engineering Technology, 2017, 37(30): 27–30. doi: 10.16815/j.cnki.11-5436/s.2017.30.003.

[9] Ru Y, Xue J K, et al. Research status and trend of real-time monitoring system for aerial pesticide spray operation. Journal of Forestry Engineering, 2023, 8(03): 21–31. doi: 10.13360/j.issn.2096-1359.202206020.

[10] Li B, Zeng L S. GPS positioning information extraction and application. Electronic Design Engineering, 2012, 20(12): 72–74. doi: 10.14022/j.cnki.dzsjgc.2012.12.023.

[11] Hu T. Development status and strategy of smart agriculture in Jilin Province. Special Economic Animals and Plants, 2022, 25(12): 188-190. doi: none.

[12] Liao J, Zang Y, Zhou Z Y, Luo X W. Quality evaluation method and optimization of operating parameters in crop aerial spraying technology. Transactions of the Chinese Society of Agricultural Engineering, 2015, 31(S2): 38–46. doi: none.

[13] Yao W X, Lan Y B, et al. Droplet drift characteristics of aerial spraying of AS350B3e helicopter. Transactions of the Chinese Society of Agricultural Engineering, 2017, 33(22): 75-83. doi: none.

[14] Lu J Q, Lin J H, et al. Classification model for citrus canopy spraying deposition based on multi-scale feature fusion. Transactions of the Chinese Society of Agricultural Engineering, 2020, 36(23): 70–76. doi: 10.11975/j.issn.1002-6819.2020.23.008.

[15] Wang G B, Li X H, et al. Quality testing of spraying by two large helicopters in rice fields and observation of preventive effect against rice blast. China Plant Protection Journal, 2014, 34(S1): 6–11. doi: none.

[16] Qin W C, Xue X Y, et al. Effects of spraying parameters of unmanned aerial vehicle on droplets deposition distribution of maize canopies. Transactions of the Chinese Society of Agricultural Engineering, 2014, 30(05): 50–56. doi: none.

[17] Wang J, Lan Y B, et al. Effects of working height of single-rotor unmanned aerial vehicle on drift and droplets deposition distribution of areca tree. Transactions of the Chinese Society for Agricultural Machinery, 2019, 50(07): 109–119. doi: 10.6041/j.issn.1000-1298.2019.07.011.

[18] Wang J, Lan Y B, et al. Meteorological and flight altitude effects on deposition,penetration,and drift in pineapple aerial spraying. Asia-Pacific Journal of Chemical Engineering, 2020, 15(1): e2382. doi: 10.1002/apj.2382.