Design and test of operation parameters for rice air broadcasting by unmanned aerial vehicle

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Abstract: Considering the difficulty of broadcasting in the small plots and complex terrain in South China, this research aimed to explore a new efficient broadcasting way and figure out advisable operation parameters by using a hollow 12-axis, rotor-wing Unmanned Aerial Vehicle (UAV) which is typically made up of four groups of solid support structure, with each consisting of three axes and two rotor wings. A 3.7 L reverse pyramid-shape seed hopper with a 60 mm×13 mm rectangular outlet at the bottom was designed to realize self-gravity seeding. Rice seed firstly directly falls on the rotating disc driven by direct-current dynamo before being sown. The disc was located 120 mm above the ground, with a diameter of 350 mm. Under constant flight conditions, parameters of the on-board broadcasting devices (dropping speed referring to speed for the outlet and the broadcasting speed for the disc's rotation speed) determine the uniformity of air broadcasting. The FUTABA T8FG transmitter and receiver system were employed as the remote control device. When the UAV flies at 3 m/s and 2 m above the ground with an expected seeding of 180 grain/m^2, the RD (Right Down) knob marked 29 and LD (Left Down) knob marked -24 with a disc rotation speed of 900 r/min, the broadcasting lasts for 15 seconds with a 25% opening (1.95 cm^2) of rectangular outlet. In order to verify the feasibility of air broadcasting parameters, the project team carried out a field broadcasting test by using a hollow multi-rotor UAV at Zhongluotan Test Base in Guangzhou in July, 2014. In the square field plots of 0.09 hm^2, flying path of air broadcasting operation was designed. The collected sampling data of broadcasting quantity per unit area after the test showed that there were, on average, 187.4 grains/m^2 of the five sampling points with a standard deviation of 22.77, and a coefficient of variation of 12.15% which was far smaller than that of artificial broadcasting. The average yield of field broadcasted by UAV is 7705.5 kg/hm^2 in 2014, implying that rice air broadcasting by UAV is feasible.

Keywords: air broadcasting, test, 12-axis UAV, self-gravity seeding, operation parameters, yield, rice

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1 Introduction

As one of the most important parts of the mechanized operation, sowing can be roughly divided into direct broadcasting and seedling transplantation[1]. Air broadcasting of rice is one way of direct broadcasting that throwing a given amount of rice seeds directly into the well-tilled field. It is a light cultivation technique that

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saves labor, time and cost, and also is a valuable and practical technology that excels itself in reducing labor input and improving productivity[2,3]. As an important part of the sowing machine, broadcaster directly affects productivity, crop production and the costs of agricultural products[4,5]. At present, the centrifugal broadcaster mainly serves in rice broadcasting with the advantages of uniform drilling, labor-saving, high-efficiency and low power consumption[6].

Air broadcasting technologies have already been applied in planting rice in large-scale in the world. The manned fixed-wing aircrafts are often used for air broadcasting operation, which is applicable to large area, with high flight speed and large load[7,8]. The air-shock type and centrifugal type are two common used broadcasters on agricultural aircrafts. Owing to its simple structure and low damage rate, air-shock broadcaster is frequently used as an air broadcasting way for rice[9]. Remarkably, manned fixed-wing broadcasting is applicable to large area of connected farmlands[10,11]. These years, in the small plots and hilly lands of South China, small agricultural UAVs have been applied in field information remote sensing, supplementary pollination, applying fertilizer and spraying chemicals and obtained some achievements. Compared with the ground machines, the efficiency of air operations has been greatly improved, making it suitable for precision agriculture.

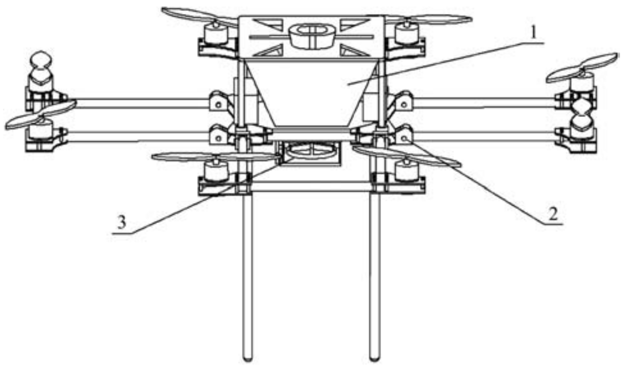
Rice is an important food crop widely planted in China[12]. Influenced by the factors such as terrain, cost and labor efficiency, et al., rice broadcasting methods vary from one place to another. Manual broadcasting still prevails in many places[13]. Considering the characteristics of small plots, hilly lands and complex terrain in South China, this paper attempts to use a small multi-rotor UAV for rice broadcasting, explores a new way of broadcasting and figures out advisable parameters of broadcasting operation.

2 Materials and methods

2.1 Air broadcasting system of UAV

2.1.1 System structure

UAV broadcasting system consists of a hollow multi-rotor airframe, a self-gravity seeding box and a centrifugal broadcasting disc, as shown in Figure 1.



Note: 1. Self-gravity seeding box 2. Hollow multi-rotor airframe 3. Centrifugal broadcasting disc

Figure 1 Structure of UAV broadcasting system

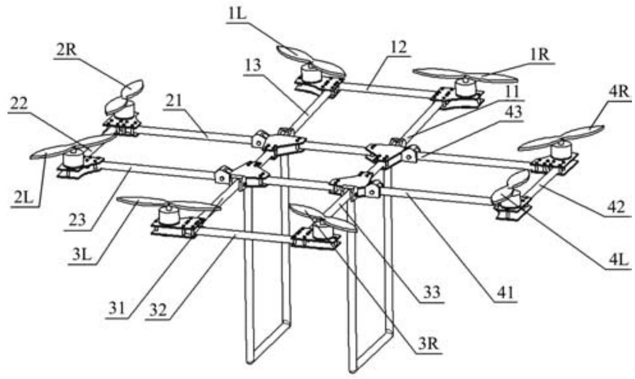
The reverse pyramid shape seeding box is placed in the hollow part of the UAV airframe as the load. Connected with the centrifugal broadcasting disc, the bottom of the seeding box distances itself from the tripod of UAV while the top is above UAV’s rotors. When filled with rice, the seeding box’s center gravity is higher than that of the UAV’s airframe. This structure is a breakthrough that enables the UAV to carry more rice without hampering UAV’s take-off and landing of UAV.

2.1.2 Hollow 12-axis, 8-rotor UAV

Traditionally and popular multi-rotor UAVs configured solid structure at the center with a symmetrical carbon fiber sheet holding the flight control system, power system and other components[14]. A holder and a camera with size smaller than the minimum size of the tripod space are fixed at the lower part of the airframe center[15]. Load is installed in the lower part of the airframe to keep the center of gravity low. The airframe is designed to ensure stability during UAV’s aerial operation, e.g. photographing[16], and the size of the designed load is aimed to save space. One of the main tasks of UAV air broadcasting is to carry load as much as possible in a single flight, but the traditional arrangement of the load at the bottom of the airframe fails to meet this requirement. Therefore, the load is placed at the center of the airframe, as shown in Figure 2, where the control system and battery are placed on the chassis of the hollow frame.

In order to maintain better stability during air operation, different from the traditional airframe structure of eight axes and eight rotors, an airframe consisting of

12 axes and eight rotors was designed. Each group support structure is made up of three axes and two rotors, contributing to the typical stable 4-axis supporting structure. In the traditional structure of eight axes and eight rotors, each rotor is supported by only one axis, and the eight axes must be on the same leveling surface to ensure stable flight[17]. However, since the speed of each rotor is different, the force of rotor acting on the axis varies from one to another when carrying load, thus causing the shift of shaft arm, then making the rotors no longer leveling to each other, and eventually leading to instability of the airframe[18,19]. To make a sharp contrast, the proposed structure of hollow 12-axis UAV is strengthened by a shaft arm between every two adjacent rotors in four symmetric directions so that the shift of shaft arm can be avoided. In this case, three axes are used to support two rotors in every symmetrical direction, leading to better flight stability when compared with that of the traditional structure. Table 1 describes the parameters of 12-axis UAV.



Note: 1R. Rotor 1 1L. Rotor 2 2R. Rotor 3 2L. Rotor 4 3L. Rotor 5 3R. Rotor 6 4L. Rotor 7 4R. Rotor 8 11 and 13. Support Arm Group 1 21 and 23. Support Arm Group 2 31 and 33. Support Arm Group 3 41 and 43. Support Arm Group 4

Figure 2 Hollow 12-axis UAV

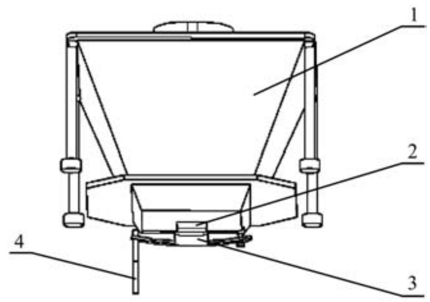
Table 1 Parameters of 12-axes rotors UAV

Maximum wheelbase/mm	Unfolding size/mm	Folding size/mm	Maximum take-off weight/kg	Maximum load /kg	Battery life /min	Cruising speed/ km·h^{-1}	Number of rotors	Size of rotor blade size/in
1200	1260×1260×650	750×750×650	18	12	10	18	8	18

2.1.3 Seeding box and seeding way

Seeding box is used to carry rice for broadcasting. Considering the limited capacity of small UAV, the seeding box was made of light materials without bearing any extra weight. To avoid using power devices, seeding mainly depends on self-gravity. To better discharge seeds, seeding box was designed like a reverse pyramid as shown in Figure 3. It can hold 3.7 L rice. At the bottom of the box, a rectangular outlet of 60 mm×13 mm is reserved. The baffle of the outlet is controlled by digital servo system connected with the remote control receiver to monitor the seeding speed of rice. Powered by 4.8 V, the 50 g digital servo system is controlled by Pulse Width Modulation[20], with an output torque of 6.6 kg/cm and a rotation speed of 0.16 s/60º.

According to self-gravity method, when the box is fully loaded, seeding is quick in the early stage, and will slow down with the rice quantity decreases. In order to realize uniform broadcasting, a special way should be adopted to cope with the seeding speed. Considering the interference factors (such as irregular rice and friction), the experiment of controlling seeding speed should be conducted in several intervals under certain conditions, which is illustrated in Section 2.2.2.

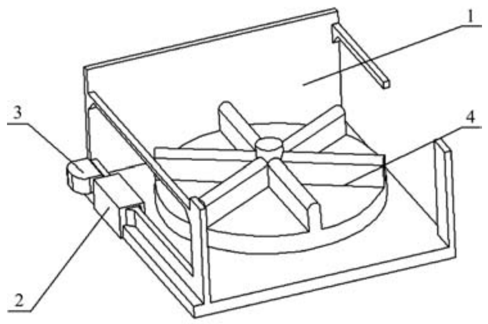


Note: 1. Seeding box 2. Seed outlet 3. Baffle 4. Digital servo

Figure 3 Self-gravity seeding box

2.1.4 Centrifugal broadcasting disc

Centrifugal broadcasting disc is composed of fixed brackets, a DC motor (direct current motor), a brush electronic speed governor and a rotating disc, as is shown in Figure 4. The brackets fix the whole broadcasting disc at the bottom of the box, and the rectangular seed outlet at the top of the rotating disc, so that the rice falls onto the rotating disc driven by DC motor and then been sown into the ground. The disc with a diameter of 350 mm is located 120 mm above the ground when the UAV is waiting on the ground. The brush electronic speed governor is connected to the remote control receiver in the same way as the digital servo is connected to the remote control receiver. The receiver receives signal of speed regulation to monitor the rotation speed of the disc. With an output current of 25 A and input voltage of 7.2 V to 12.6 V, the 23.5 g brush electronic speed governor has an internal resistance of 0.003 Ω and a BEC output (voltage-stabilized mode) of 1A/5V. In addition, the 165 g DC motor with rated voltage of 12 V, boasts a maximum speed of 1000 r/min speed under the load current of 180 mA.



Note: 1. Fixed bracket 2. DC motor 3. Brush electronic Speed governor 4. Rotating disc

Figure 4 Centrifugal broadcasting disc

Different rotation speeds will affect the initial velocity and direction of broadcasting, and then influences the radius and uniformity of broadcasting. In order to achieve uniform broadcasting, a special way should be employed to regulate the rotation speeds of the disc. In consideration of the interference factors (such as the random distribution of seeding on the disc and 2 fixed brackets in the broadcasting space), the experiment of controlling rotation speed of disc should be performed in several intervals under certain conditions, which is described in Section 2.2.2.

2.2 Design of broadcasting parameters

As the most important parameter for measuring the outcome of broadcasting operation, the uniformity of sowing is not only related to flight parameters (flight altitude, flight speed and flight route) of the UAV, but also determined by the parameters of on-board broadcasting devices (seeding speed for the outlet and broadcasting speed for rotating disc). The flight parameters of the UAV are largely determined by the driver or the input parameters of the flight control system. This research did not cover variable flight parameters, but concentrated on designing and testing the operation parameters of on-board broadcasting devices in the case of flight with constant parameters.

Under the mode of remote control, the FUTABA T8FG transmitter and receiver system (FASST-2.4G mode) was used for remote-control broadcasting. The analog signal channel knobs of RD (Right Down) and LD (Left Down) on the transmitter served as the input terminals of control signals, as depicted in Figure 5. In order to obtain broadcasting parameters in the flight of constant parameters, the positions of knob RD and LD were firstly calibrated in accordance with the opening of the outlet and the rotation speed of the disc respectively, and then the significance of single factor affecting the uniformity of broadcasting was determined.

2.2.1 Calibration of the opening and disc rotation speed

As shown in Figure 5, the scale range of the analog signal knob channel of LD and RD is −100 to 100. On the LD knob, the scale of indicator hole is marked −100 on the far left, 100 on the far right, and 0 in the middle. The transmitter sounds when LD is read 0. The scale on the RD knob is exactly the same with LD but read reversely to those on the LD.

Figure 5 Analog channel of RD&LD

The open of the seed outlet is determined by the movement of the baffle which is controlled by the received LD scale. The relationship between the outlet area and the LD scale is shown in Table 2.

Considering the measurement error and system error, the fitting of the relationship between the outlet area and LD scale (Table 2) is shown in Figure 6, while the quadratic fitted curve is expressed in Equation (1):

$$y=0.00069x^2+0.11x+4.2 \quad (-66<x<31) \qquad (1)$$

The R^2 is 0.9959 and the Adj R^2 (Adjusting R^2) is 0.9956, both are close to 1, implying a small statistical error.

Table 2 Relationship between seed outlet area and LD scale

Opening/cm^2	Scale	Opening/cm^2	Scale
0	-65	4.5	1
0	-60	4.8	4
0	-56	5.0	6
0	-51	5.4	8
0.3	-46	5.5	10
0.6	-42	5.7	12
0.9	-37	5.9	14
1.2	-32	6.3	16
1.5	-25	6.6	18
1.8	-21	6.9	20
2.4	-18	7.2	22
3.0	-11	7.3	24
3.3	-9	7.5	26
3.6	-4	7.6	28
4.2	0	7.8	30

Note: The rectangular baffle is 6 cm long and 1.3 cm wide.

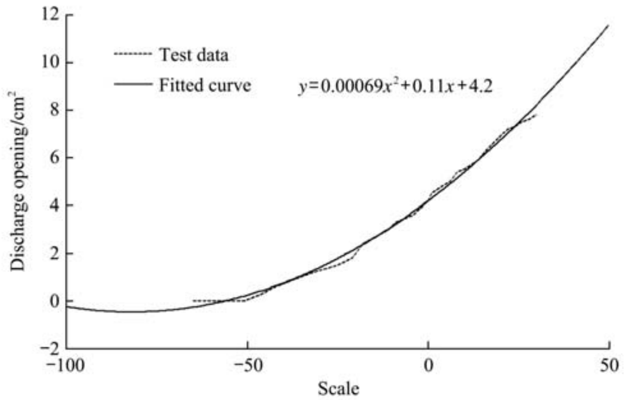


Figure 6 Fitting curve of outlet area and LD scale

Similar to the method of calibrating the outlet area, the speed of rotating disc is equal to that of the DC motor controlled by the RD scale. The tachometer was used to test the rotation speed, and the relationship between the test value and the RD scale is shown in Table 3.

Table 3 Relationship between rotation speed and RD scale

Rotation speed/r·min^{-1}	Scale	Rotation speed/r·min^{-1}	Scale
0	−100	678	−3
0	−93	693.8	0
0	−86	728.4	6
87.2	−80	778.5	16
139	−73	793.6	19
194.5	−66	830	26
256.4	−60	895	36
322.1	−53	939.6	43
386.9	−46	986	50
438	−39	1001	56
465.2	−36	1001	63
518.7	−29	1001	73
563.2	−23	1001	80
603.6	−16	1001	86
642	−9	1001	100

The range of the RD channel is wider than that of the DC motor's rotor speed. The sample points with a rotation speed of 0 r/min and an upper limit speed of 1001 r/min were removed to avoid system errors. The relationship between the rotation speed and the RD scale (Table 3) is fitted in Figure 7 while the quadratic fitted curve is expressed in Equation (2) below:

$$y=0.02x^2+6.2x+701.8 \quad (-86<x<56) \qquad (2)$$

It is figured out that the R^2 is 0.9981, and the Adj R^2 is the 0.998, indicating a small statistical error and meeting the requirements of the fitting.

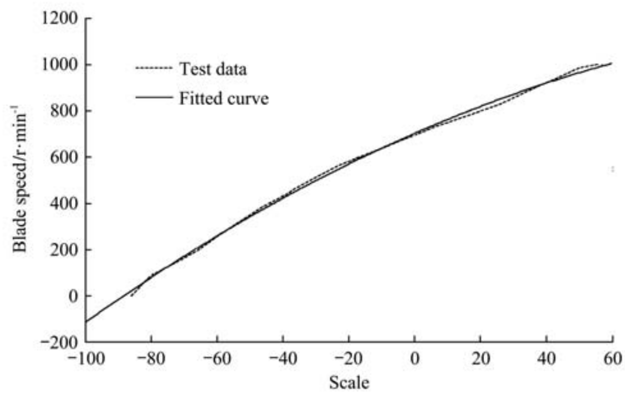


Figure 7 Fitting of rotation speed and RD scale

2.2.2 Determination of air broadcasting parameters

Under constant flight parameters, the air broadcasting uniformity of UAV mainly depends on whether the broadcasting rate is consistent throughout the operation under self-gravity when the mass changes. In the meanwhile, the expected broadcasting number of seeds per unit is co-determined by the seeding speed and the rotation speed of disc.

(1) Test of uniformity in self-gravity seeding

If the outlet area of seeding box is not effectively controlled, self-gravity will decide the seeding speed—quick at the beginning and slow later. Both the bottom radian of seed box and the friction on the rice surface determine the retention amount of rice in later stage of broadcasting. Under different open size of the outlet, a self-gravity seeding test was conducted on the rice seeds with a same weight.

Table 4 shows the broadcasting time and retention amount. It is found that seeding speed increases as the enlarging of outlet area. When the outlet area opens over 50%, the speed of broadcasting increased and the retention amount of rice decreased significantly, which improving the efficiency of broadcasting. Even under the same broadcasting operating conditions, the irregular shape of rice and the friction between rice and the seeding box jointly account for bigger error of broadcasting parameters. The maximum error of various parameters appears at a 25% opening. Correspondingly, the standard deviation of time consumption is 2.683, while that of the retention is 26.95, and that of the retention after stirring is 16.19. The last columns of Table 4 are the results of using the vibration motor to stir the held-up rice in the seeding box, which are employed to simulate the real vibration of UAV during its flight.

Table 4 Different broadcasting time and retention of rice in varying opening

Opening	Number	Time/s	Retention/g	Retention after stirring/g
25%	1	24.58	246.90	180.20
25%	2	20.35	250.00	205.60
25%	3	25.29	192.60	167.30
25%	4	20.28	241.10	190.30
50%	1	9.57	122.40	86.20
50%	2	9.83	102.40	83.70
50%	3	8.76	107.70	75.50
50%	4	9.56	99.90	76.30
75%	1	7.59	38.50	33.30
75%	2	4.70	34.20	25.70
75%	3	5.95	25.20	16.80
75%	4	7.07	30.80	25.50
100%	1	3.29	0.00	0.00
100%	2	3.52	0.00	0.00
100%	3	3.97	0.00	0.00
100%	4	3.73	0.00	0.00

Note: The time of stirring is not included in the time consumed. The total weight of rice tested is 1697.50 g.

(2) Design of broadcasting parameters

The UAV is supposed to fly straight at a constant velocity v (3 m/s) and height h (2 m). Moreover, the broadcasting parameters are designed to reach the broadcasting target of 180 grain/m^2. Control variables need to be reduced as much as possible during UAV's operation while the disc keeps rotating at a high speed so as to reach the maximum range of broadcasting. Therefore, controlling the seed outlet area can regulate the rice number per square meter. In order to improve the efficiency of broadcasting, the disc with a diameter d of 350 mm rotates at a high level of 900 r/min. Every 100 grains weighs 2.37 g on average. Theoretically, the falling time of rice t is expressed as follows:

$$t = \sqrt{\frac{2h}{g}} = 0.408 \text{ s} \tag{3}$$

The rice falls on the rotating disc from seeding box due to self-gravity, and the positions of acting force between the rice and blades scatter randomly from the center to the edge. Therefore, half of the original radius is taken as the radius of rice broadcasting on the ground, so the average velocity of the rotation V can be concluded as below:

$$V = n\frac{2\pi}{60}\frac{d}{2}\frac{1}{2} = 8.243 \text{ m/s} \tag{4}$$

The rice broadcasting distance L in the horizontal direction on one side of the UAV is:

$$L = tV = 3.363 \text{ m} \tag{5}$$

When the UAV flies at 3 m/s bearing the goal of broadcasting 180 grain/m^2, the rice mass m required in 1 second is:

$$m = \frac{2L \cdot v \times 180 \times 2.37}{100} = 86.078 \text{ g} \tag{6}$$

The designed seeding speed is 86 g/s. Figure 8 shows the different seeding speeds corresponding to varying outlet areas of self-gravity.

In Figure 8, the first 15 points (first 15 s) in the curve with a 26% outlet open percentage are fitted in a straight line with a corresponding seeding speed of 92 g/s, which is closed to the designed speed. Seeding speeds corresponding to openings of more than 50% are much higher than the designed one. Therefore, the appropriate open percentage is expected to be found around 25% while finding out the advisable seeding speed (later 15 s) can make the whole curve a straight line at best and eventually achieve uniform seeding.

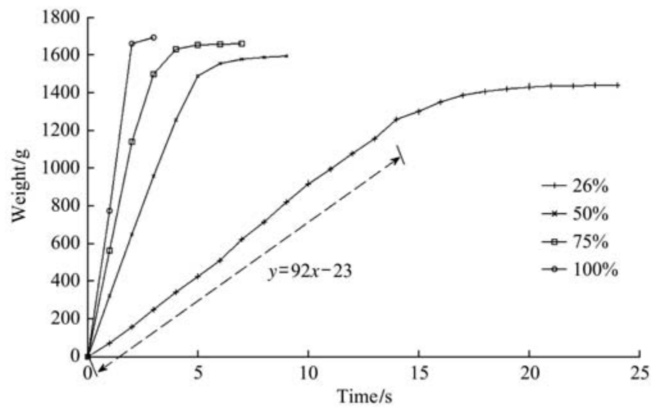


Figure 8 Different seeding speeds

In Figure 9, the seeding test under self-gravity with a 25% opening is repeated for 4 times, in consideration of the uncontrollable factors in seeding, such as the friction between the rice and seed boxing, as well as the rolling of the rice. Under the same conditions, the 4 curves labeled a, b, c and d are with slight differences. The equations in Figure 9 are fitted from each other's linear data of the curves in the first 15 s. It is learned from Figure 9 that the seeding speed of Test C is 87 g/s, which is consistent with the designed parameter. The maximum seeding speed of 95 g/s appears in Test B while the minimum seeding speed of 79 g/s appears in Test D. Take Test D with the minimum seeding speed as an example, the mass of seeded rice is 1297 g in the first 15 seconds, which accounts for 89% of the total mass of rice in the seeding box. During 15-20 s, the seeding speed is significantly slower with 11% of the total seeding rice. In order to simplify the design of broadcasting parameters and improve the efficiency of broadcasting, it is advisable to broadcast in the first 15 s, and then close the seed outlet.

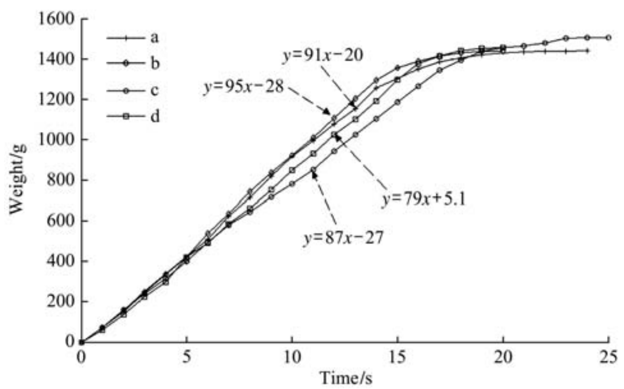


Figure 9 Four speeds of 25% opening

(3) Determination of broadcasting parameters

When the UAV flies in a straight line at a constant velocity v (3 m/s) and at a designed height h (2 m), the broadcasting parameters are designed to reach the broadcasting target of 180 grain/m^2. The rotation speed of broadcasting disc n determined in Section 2.2.2 is 900 r/min. Then by substituting n into Equation (2), the RD knob scale of 29 is obtained. It is known from Figure 9 that the broadcasting lasts for 15 s with 25% of seed outlet. Table 2 shows that the opening is 1.95 cm^2, which is then substituted into Equation (1) to produce the LD knob scale of −24.

3 Results and discussion

3.1 Field test of air broadcasting

3.1.1 Testing procedure

In order to verify the feasibility of broadcasting parameters, the project group carried out field test of air broadcasting by using hollow multi-rotor UAV at Zhongluotan Test Base, Guangzhou in in July, 2014.

A square field of 0.09 hm^2 was selected as the test site as shown in Figure 10, where low ridges stand on its both sides. Characterized by wide vision with no obstruction, this field is suitable for the UAV to fly along the ridges. Outside the front ridge is the flat cement pavement without poles in sight. However, at the rear ridge, there is a row of trees, which imposes potential threat for UVA's straight flight vertical to the rear ridge. Therefore, the flight path is designed as depicted in Figure 10s. The flight path consists of the trajectory of broadcasting operation and that of the UAV's movement. Section f of the broadcasting trajectory is parallel to the rear ridge, which can effectively minimize the influence of trees and other obstacles on UAV's flight parameters.

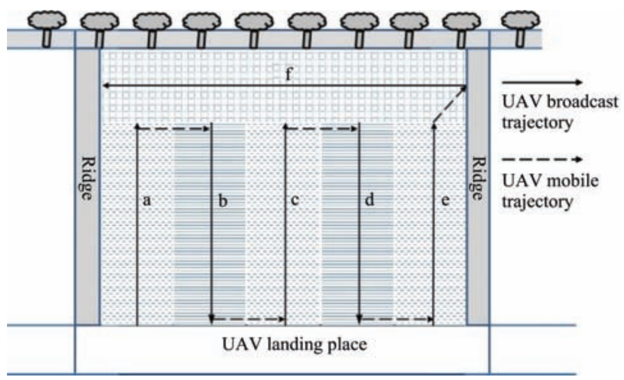


Figure 10 Field and flight trajectory

Considering the flight height of only 2 m, the low accurate positioning capability of the flight control system and the safety, the authors adopt assisted driving and flight parameters supervision through manned remote control in the place of autonomous route driving The hollow 12-axis, 8-rotor UAV was operates strictly in line with the flight parameters and air broadcasting parameters as stated in section 2.2.2 s. In view of the battery life and supplement of rice seeds, the air operation has to interrupt and then the UAV returns to recharge. The position at which the operation interrupts is recorded and then the UAV restarts from that exact position.

Moreover, all essential parameters should be ensured and recorded during UAV's single broadcasting within the first 15 s.

3.1.2 Test sampling

A self-designed square measuring tool made of four rods (1 m^2) was employed to determine the unit area where samples were taken. Six analyzed random sampling points contributes to the data in Table 5.

As shown in Table 5, the variation of flight parameters during the flight inevitably affected the broadcasting rate. As an obvious error point, Point 4 was excluded from analysis. The average of the rest five points is 187.4 grain/m^2 and the standard deviation stands at 22.77 with the variation coefficient of 12.15%, which is far smaller than that of manual broadcasting.

Table 5 Results of field investigation

Random sampling points	1	2	3	4	5	6
Broadcasting rate/Grain·m^{-2}	155	182	205	91	213	182

3.1.3 Results of rice yield

Yield measurement was performed at Zhongluotan Test Base, Guangzhou, in November, 2014, as shown in Figure 11. Three sampling points measuring 1 m^2 each were selected to count the quantity of plants and productive ears, each point. The whole field was harvested by machine, and the actual harvest data were then calculated. According to the national standard of rice moisture content of 13.5%, the average yield is 7705.5 kg/hm^2 after eliminating water and impurities. In every square meter, the field yield results show that there are 321 productive ears and 38 holes on average, which proves that air broadcasting by using UAV is not only feasible, but also efficient and economical.

Figure 11 Test plots for measuring yield

4 Conclusions

Based on the hollow 12-axis, 8-rotor UAV, this paper explores the construction of rice air broadcasting system by utilizing self-gravity. The authors design the on-board broadcasting devices composed of an airframe structure, self-gravity seeding box and the centrifugal broadcasting disc. Operation parameters were designed and determined, and a field test using UAV's air broadcasting system was also conducted before drawing the following conclusions:

1) Fixed in the middle of the hollow 12 axis, 8-rotors UAV, the self-gravity seeding box, together with the centrifugal broadcasting disc stabilizes UAV's state of flight. Compared with other UAV structures, this airframe is simple but reliable, and capable of effectively increasing the load and improving the flight performance.

2) When the UAV flies in a straight line at a constant velocity v (3 m/s) and a designed height h (2 m) with the broadcasting target of 180 grain/m^2, the RD knob scale reads 29 and the LD knob scale marks 24 with the rotation speed of 900 r/min. The broadcasting lasts for 15 seconds with a 25% opening of seed outlet (1.95 cm^2).

3) Sampling results of the test show that the average of the remaining five samples points is 187.4 grain/m^2 while the standard deviation is 22.77 and the coefficient of variation is 12.15%, which is far smaller than that of manual broadcasting. Average yield of air broadcasting conducted by UAV is 7705.5 kg/hm^2 after eliminating water and impurities.

The test shows that it is practical and feasible to broadcast rice by using an UAV, but there are still some problems requiring further study:

1) Although the broadcasting system by self-gravity has the advantages of simple structure and light weight, the system cannot ensure consistent seeding speed, which shorts valid broadcasting time and reduces the broadcasting efficiency. To this end, the precision seeding by UAV needs to be further investigated.

2) This research is limited to fixed flight parameters of UAV. It is still difficult to avoid the change of flight parameters during UAV's operations. Attention should be paid to studying the automatic control system with

variable broadcasting parameters in accordance with the change of flight parameters.

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