Single Rotor Mini Reconnaissance Aircraft Design

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Abstract. The micro rotor aircraft has the advantages of small noise, good concealment and so on, which make it has wide application potential in both military and civilian applications. Aiming at the problems of public security organs such as counter-terrorism, anti-drugs, and disaster relief, a single-rotor wing micro-reconnaissance aircraft was designed. In this paper, the structure of the aircraft is analyzed and designed. Secondly, the aerodynamic characteristics and adsorption capacity of the aircraft are analyzed. Finally, the work flow of the UAV is introduced. The UAV can achieve multi-directional flight, vertical take-off and landing and hovering, and has good prospects for investigation and surveillance.

1. Introduction

Rotor-type micro-aircraft use rotor rotation to generate lift to provide power, enabling vertical take-off and landing and hovering in the narrow space environment and rapid movement within complex buildings, providing good concealment and stability, due to its modern military and civilian use. There are wide application potentials in various fields, and the world's advanced countries have extensively carried out research and development of micro-aircraft bodies and their subsystems. At present, there are several kinds of rotor micro-aircrafts that have been successfully developed in foreign countries: Lutronix's Hummingbird, Honeywell's "Unmanned Aircraft", United Aerospace's "ISTAR" and Georgia Tech's "GTSpy" [1].

Domestically, research on micro-aircraft has also started in the late 1990s, among which the more mature ones are the fixed-wing MAV of Nanjing University of Aeronautics and Astronautics, the micro-gyroplane of Shanghai Jiao Tong University, and the flapping wing of Northwestern Polytechnical University [2]. Some aviation academies such as Beijing University of Aeronautics and Astronautics, Harbin Institute of Technology and several scientific research institutes are also actively researching micro-aircraft, and they have very good research results in some related technologies.

2. Design Concept

The work is mainly designed based on the following two aspects:

The first is a single rotor micro-drone. According to the design principle of dragonfly, a single rotor unmanned aerial vehicle is designed. The UAV has only one rotor. The structure is simple. The balance control method is different from the ordinary rotor. It sets up a funnel shaped air duct in the middle of the body, and collects the airflow generated by the rotor rotating when the aircraft flies and divides the

airframe in four directions. 4 blowholes are set to control the direction of air flow through a solenoid valve. When the UAV flight changes direction, the solenoid valve opens the corresponding air hole and jet to the opposite direction, in order to control the flight direction of the UAV.

The second is the adsorption type reconnaissance device. The suction cup is set at the bottom of the body of the drone, which can be attached to a smooth object such as a wall surface to save energy consumption and increase the life time. Infrared imaging devices or high-sensitivity listeners are installed to easily complete hovering and other difficult operations. It is suitable for flying in indoor and other narrow spaces and complex terrain areas, and has excellent flight maneuverability.

3. Drone Structure Design

3.1. Rotor Wing Design
a Selection of airfoil

Summarized the shape of the rotor wing mainly divided into the following four categories. Later airfoils are developed from these four shapes. Common wing shaped is shown in Fig. 1[3, 4]:
The respective characteristics of these four airfoils are as follows:

Figure.1 Common Airfoil Types

The upper and lower arcs of the symmetric airfoil are symmetrical according to the chord; the drag coefficient and lift-to-drag ratio of the airfoil are small; the upper arc of the double-convex airfoil is larger than the arc of the lower arc, but both arcs protrude outward. The lift-resistance of this airfoil is slightly larger than that of the symmetric one; the upper arc of the plano-convex airfoil protrudes, and the lower arc and the chord basically coincide. The maximum lift-to-drag ratio of this airfoil is larger than that of the biconvex type; the upper arc of the concave-convex airfoil is convex outwards and the lower arc is concave inwards. It is proved by experiments that this airfoil has large lift and a large lift-to-drag ratio, which is suitable for small rotor blades. Considering comprehensively, the concave-convex airfoil is chosen as the rotor's rotor airfoil [5].

b Airfoil geometry parameters

The airfoil is the longitudinal section of the wing, and its aerodynamic characteristics have an important influence on the overall characteristics of the wing and the aircraft. The main geometric parameters of the airfoil definition is shown in Fig.2:
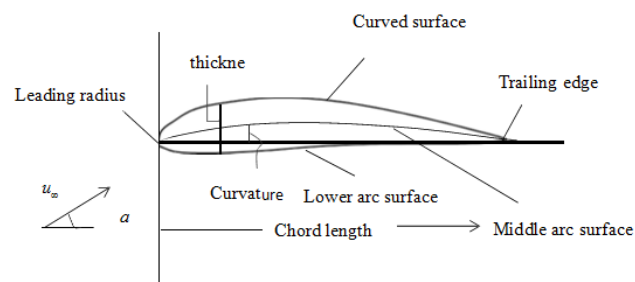

Figure.2. Airfoil geometry parameter definition

c Rotor blade design

The design of the rotor blade is mainly to increase the lift force and make it as low as possible. Since the rotation of the rotor in this paper is directly driven by the motor, the lift force is adjusted by the rotation speed of the motor, so the paddle adopts a fixed paddle moment. As long as a reasonable installation angle is ensured, a good lift can be produced at a certain blade radius and speed. IN order to have better lift, it is necessary to make the rotor more solid, so the rotor blades are designed to be two pieces. Due to the small diameter of the hub, the chords of the blades are smaller in order to allow the blades to be distributed on the hub.

The parameters for designing the blade in this paper are as follows: The blade diameter D is 50mm, the installation angle of the blade is 15°, the installation angle of the blade tip is 5°, and the diameter d of the hub is 2mm. The blades are directly connected to the hub, there is no torque, and the blades are chopped. The specific structure is shown in Fig. :
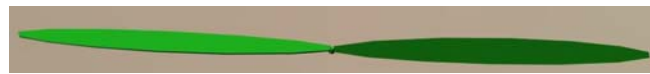

Figure.3. Rotor 3D Structure

d Rotor lift

The design of the rotor blade is mainly to increase the lift force and make it as low as possible. Since the rotation of the rotor in this paper is directly driven by the motor, the lift force is adjusted by the rotation speed of the motor, so the paddle adopts a fixed paddle moment. As long as a reasonable installation angle is ensured, a good lift can be produced at a certain blade radius and speed. IN order to have better lift, it is necessary to make the rotor more solid, so the rotor blades are designed to be two pieces. Due to the small diameter of the hub, the chords of the blades are smaller in order to allow the blades to be distributed on the hub.

The tension generated by rotors is the main reason that drones can hover in the air. The action of the rotor blade itself is similar to that of the fixed wing. It constantly rotates to generate tension so that it can lift or hover vertically in the air against gravity.
Rotor's pull formula is:

$$\mathrm{T} = \rho A(\Omega R)^2 C_T \tag{1}$$

In the formula,T is the pulling force when the blade rotates,ρ is the air density,A is the area where the blade rotates,Ω is the rotation speed,R is the rotor length,C_T is the coefficient of pull. From the equation, it can be concluded that the rotor does not increase the pulling force by increasing the forward flight speed, but rather increases by the rotation speed of the rotor. Therefore, it is possible to achieve aircraft flight modes such as ascending, descending and hovering by controlling the rotation speed of the rotor.

The rotor micro unmanned aerial vehicle is flying under the low Reynolds number [6], so the air viscosity is larger and its dynamic characteristics are very different from the conventional rotor aircraft, so the helicopter dynamic principle can not be directly used for the micro rotor unmanned aircraft. Micro-rotor drone we usually use leaf pheromone analysis [7], leaf element is a small blade. The principle of the leaf pheromone method is to regard the blade profile as an airfoil, and then analyze and calculate the aerodynamic force of the airfoil. Finally, the blade leaf force and the aerodynamic torque are integrated from the blade root to the blade tip, and then the blade is multiplied by the blade. Count, the final total aerodynamic force and total aerodynamic torque are obtained [8].

3.2. Cameras and Listener
The connecting rod of the rotor and the motor is designed as a three-layered cylinder. The innermost layer is the solid shaft connecting the rotor and the motor. The motor rotates the rotor to provide the lift of the aircraft. The camera is set in the second layer connecting rod and can rotate 360 degrees to capture

the image and video during the investigation, and the captured image video can be transmitted in real time.At the same time, the built-in listener can monitor the target anytime and anywhere. The three-dimensional structure of the connecting rod and camera is shown in Fig.4:
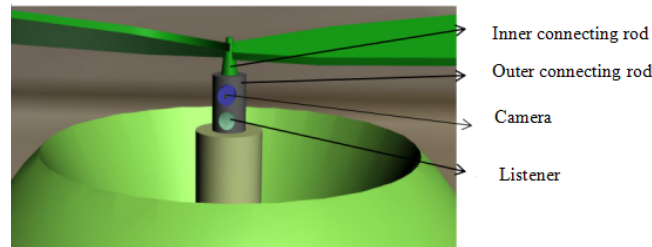

Figure.4. Three-dimensional structure diagram of connecting rod and camera

3.3. Wind Tunnel Design

Rotor at high speed, can be seen as a paddle with numerous blades, its thickness can be seen as zero, and can produce pressure difference and withstand torque. According to the force and reaction force of Newton's theorem, when the air passes through the paddle at a certain speed, the paddle plate bears the effect of the air on it, and it will inevitably give the air a reaction force of the same magnitude in the opposite direction, thus forming a pulling force. Assuming that the incoming air is an incompressible ideal fluid, according to Bernoulli's Law, as shown in Fig.5.
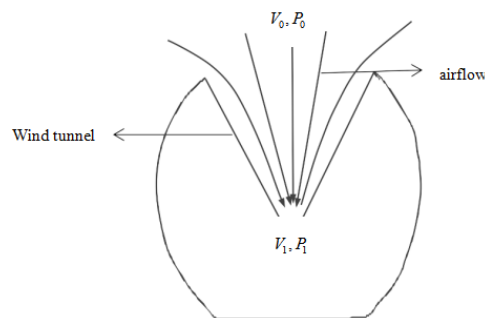

Figure.5. Air flow field diagram

Assume that the axial velocity of the fluid above the air duct is V_0 and the pressure is P_0.When the rotor rotates at high speed, the fluid above the air duct is sucked into the air duct. At this time, the axial velocity of the fluid is V_1 and the pressure is P_1.According to the law of continuity, the flow velocity is slow in the area where the flow field section is large, and the flow velocity is fast in the area where the flow field section is small. When the fluid passes through, the flow field is limited due to the passage, and the flow field cross section changes from large to small. Therefore, the velocity of the fluid passing through the air passage becomes larger and the pressure becomes smaller. The shape of the flow field is like a "funnel" as shown in the diagram.

According to the Bernoulli theorem and the conservation of momentum and energy, the power generated by the air duct can be calculated without considering various external factors. The Bernoulli formula can be obtained by:

$$\frac{1}{2}\rho V_0^2 + P_0 = \frac{1}{2}\rho V_1^2 \tag{2}$$

The total power generated by the duct according to the law of conservation of momentum is:

$$\text{T} = \text{m}V_1 - mV_0 \tag{3}$$

Among them, m is the mass flow rate through the air duct per unit time, and mV_0 and mV_1 are the unit air currents upstream and downstream unit air momentum.

The three-dimensional model of the air duct is shown in Figure 6. The diameter of the duct is 15mm, the diameter of the bottom is 3mm, and the height of the duct is 10mm.
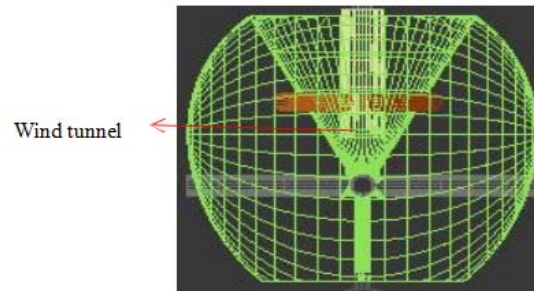

Figure.6. Wind tunnel three-dimensional model

3.4. Fuselage and air vent design

Single-rotor micro-vehicle has many advantages compared with ordinary rotor craft. It has a simple structure, only one motor control, and it is easier to achieve miniaturization. And the noise is small and it is not easy to be found. It is more suitable for investigation and surveillance. Its balance control method is simple. It uses the air duct in the middle of the fuselage to collect the lower wash flow of the rotor. Four air holes are set in the four directions of the air frame. The direction of air flow is controlled by the solenoid valve to achieve the forward flight, backward movement and deviation of the aircraft. Airlines. Therefore, this article uses the air duct as the main body of the fuselage on the basis of the single rotor layout.

1) Fuselage: Initially the fuselage shell is ellipsoidal, with a diameter of 20mm. The surface of the fuselage is covered with a layer of highly reflective material, which can map the surrounding environment to the fuselage, so that the aircraft and the surrounding environment can be integrated to achieve the purpose of stealth. The central part of the fuselage is equipped with air ducts for collecting rotor air flow. Specific dimensions have been given in the previous section. When the rotors rotate at high speed, the air flow is sucked into the air duct to provide power for attitude control of the aircraft.

2) Stoma: In addition to the vertical take-off and landing of the micro-drone, it also has the functions of forward flight, back, and yaw. In order to realize these functions, we set 4 air holes in each direction of the body, and control the opening and closing of the air holes through the solenoid valve, thus changing the direction of the air flow, to achieve the forward flight, backwards and yaw of the aircraft. The pore diameter is 3mm. The three-dimensional structure of the fuselage and stomata is shown in Fig.7:
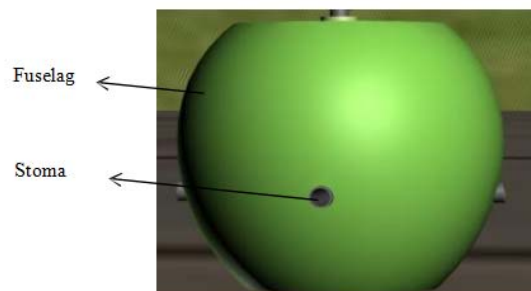

Figure.7. Fuselage and stomata 3D model

3.5. Fuselage and air vent design

A vacuum suction cup is set at the bottom of the body to allow it to be attached to a smooth object such as a wall surface, thereby saving energy consumption and improving battery life. A suction hole is set inside the suction cup, and the air hole switch is controlled by a solenoid valve to control sucker suction and discharge. The diameter of the suction cup is set to 10mm, and the diameter of the internal air hole is set to 3mm.The sucker's three-dimensional structure is shown in Fig.8.
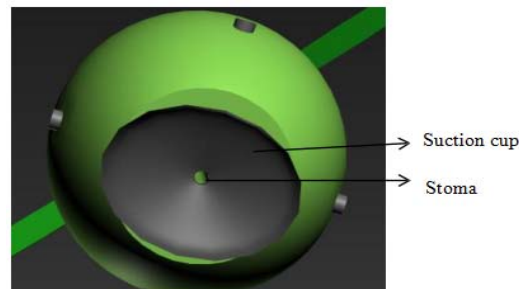

Figure.8. Suction cup three-dimensional structure diagram

4. Aircraft Workflow

Fig.9 shows the aircraft workflow.The single-rotor, mini-reconnaissance drone takes off after receiving the investigation mission, and the aircraft rotor rotates at high speed, and the generated lift overcomes its own gravity and takes off vertically (as shown in a).During the flight, infrared sensors and ultrasonic sensors can detect obstacles in flight. The air duct in the middle of the fuselage collects the lower washing flow of the rotor, and controls the corresponding air hole switch through the solenoid valve to avoid obstacles in the flight to ensure the surrounding obstacles. The safety of the aircraft (as shown in b).

After the aircraft reaches the mission location, the aircraft is close to the wall and other objects that can be adsorbed, and the solenoid valve is controlled to open the air hole inside the suction cup. The aircraft presses down the air inside the suction cup and closes the air hole. The suction cup is adsorbed on the object (as shown in c) and passes through the needle. Hole cameras and mini listeners perform listening tasks (as shown in d).
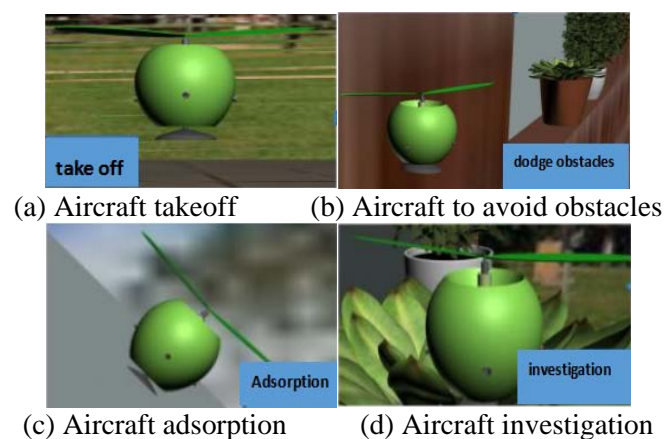

(a) Aircraft takeoff   (b) Aircraft to avoid obstacles

(c) Aircraft adsorption   (d) Aircraft investigation

Figure.9. Aircraft Workflow

After the task is completed, the control solenoid valve opens the air hole in the suction cup, the air enters the suction cup, and the aircraft leaves the adsorption object and lands on the ground.

5. Aircraft Parameters

The aircraft has good performance, the remote control signal can be automatically returned when the signal is interrupted. When the power is insufficient, it can automatically alarm and automatic landing, and can watch the high definition video in real time at the ground station, and save the high definition frequency in the aircraft. The overall three-dimensional rendering of a single-rotor mini-aircraft is shown in Fig.10:
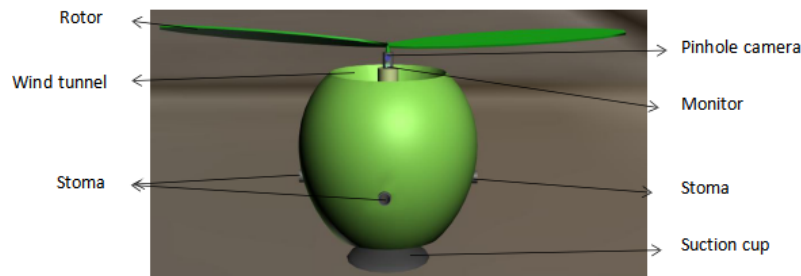

Figure.10. Aircraft Overall 3D Model

The parameters of the single rotor mini aircraft are shown in Tab.1

Table I. Single Rotor Mini Aircraft Parameters

Content	Parameter Value
Maximum load	20mm
Rotor diameter	50mm
Flight diameter	≥2km
Maximum flight altitude	500m
Aircraft weight	18g
Maximum take-off weight	<18g

6. Conclusion

Based on the difficult problem of criminal investigation in public security organs in today's society, this paper designs a single rotating wing Mini reconnaissance aircraft. Looking at the development status of micro-rotorcraft at home and abroad, on the basis of studying the structure of drones, the aerodynamic characteristics are also analyzed, and the workflow and parameters of drones are described.

This aircraft is a micro-aircraft. It differs from ordinary rotorcraft in that it has only one rotor and is controlled by a miniature motor. Its internal structure is simple, it can be designed very small, and because there are few moving parts, it produces little noise and is not easily detected. It has good concealment, can show its own advantages and strong usability in civil, police, and military use, and has good prospects for development.

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