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Study on the Simulation of Flapping-Wing Aircraft

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Abstract. Based on the research status of flapping-wing aircraft at home and abroad, the overall scheme of bionic flapping-wing aircraft is established in this paper. In the aspect of trajectory planning, the three-dimensional modeling and simulation analysis of bionic flapping-wing aircraft are carried out, and a new flapping-wing mechanism is adopted. Finally, the trajectory of flapping-wing aircraft is analyzed from the point of view of the operation, and verification experiments are carried out to obtain the best flapping-wing effect.

Keywords. flapping wing flight; Three-dimensional modeling; Simulation analysis

1. Introduction

With the rapid development of modern electronic computers, new composite materials, control technology, and other high-tech fields, there is hope for the research and development of ornithopters on this basis. At present, it has been possible to produce close to the practical type of autonomous control flapping wing aircraft. The principle of these aircraft is basically divided into two categories: bird-like flapping wings and insect-like flapping wings. Most of them are small unmanned ornithopters, while a few are large manned ornithopters that can make test flights. The flapping frequency of imitation birds is low, which is due to the large wing area of birds. Its flight is similar to that of birds, so it is relatively easy to make. The flapping frequency of the imitation insect wing is high, which is because the insect wing area is small, so the number of flapping needs to be increased to improve the lift, so the production is relatively difficult, but the imitation insect can conveniently achieve hovering. But generally speaking, the research of medium and large ornithopters is still in its infancy, and the overall level belongs to the blue ocean [1].

2. Overall Structure Design

The fuselage of the bionic ornithopter is an important part of its design. As a

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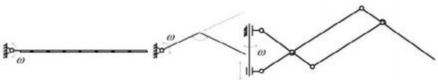
component connecting the wings, tail, and nose, the fuselage is also a platform for carrying avionics equipment and load equipment. Since the bionic design is based on the dove, the shape of the dove should be imitated in the fuselage structure design. The modeling software Inventor is used to design a bionic ornithopter shape digital model, as shown in Figure 1. The whole fuselage and nose can be seen the design of the fuselage and nose imitate the body shape of the pigeon, with a certain streamlining, to reduce a part of the flight resistance in the air [2]. Since the fuselage is the largest part of the ornithopter, the choice of design materials is also very important. The skin material has the characteristics of a certain strength and light weight. According to the relevant material information, the bionic aircraft body is made of high-strength glass fiber or carbon fiber composite material, and it is formed once by the negative mold laying heating and curing method. It has superior structural strength and stiffness characteristics, and the unique thin-wall structure maximized the space inside the body, with lightweight and impact resistance [3].

Figure 1. Three-dimensional view of ornithopter

3. Aerodynamic Design of Flapping Wing and Tail Wing

The flapping area is increased in the process of underwing flapping and reduced in the process of the upward lifting to achieve a positive lift in one flapping cycle [4]. By summarizing and studying the existing flight deformation modes of flapping wings and combining them with the design requirements of this paper, three deformation modes are mainly designed in this section, as shown in Figure 2.



(1) Swing mechanism (2) Swing folding wing type

(3) Bidirectional movement type compound mechanism

Figure 2. Flight deformation pattern of the flapping wing

Scheme 1: In the flapping process of birds, the feathers open to reduce air resistance in the up-lifting stage, and close to increase the flapping area in the down-flapping stage. According to this principle, the deformation mode is designed to achieve positive lift in one cycle by changing the area of the up-and-down flapping [5]. The black part is the stomata, which is closed when the downward flapping and opened when the upward-lifting, as shown in Figure 2(1).

Scheme 2: Generally, large birds have two or more wings. In the flapping process, the wings are fully unfolded in the descending flapping stage, and a certain folding Angle is formed in the ascending stage. According to this principle, the deformation mode in Figure 2(2) is designed. The up-and-down flapping area is changed by folding.

Scheme 3: Birds that use this deformation mode of flight, such as bats, have high flight efficiency and flexible flight process. In the flight process of bats, continuous flight can be realized by the intermittent flapping of wings, and rapid return-back can be realized by changing the shape of wings when flying straight. According to the deformation process of bat wings, the deformation mode shown in Figure 2(3) is designed. The up-and-down flapping area of the change is folded horizontally [6].

The three scenarios are summarized in Table 1.

Table 1 Deformation scheme table

Category	Option 1	Option 2	Option 3
Deformation mode	Lower Blowhole closed and Upper Blowhole opened	Through the mechanism design, it folds and unfolds when flapping	The wings open and close when fluttering
Effective flutter area	Moderate	Less	More
Number of drivers required	1. The wings fluttered up and down 2. The opening and closing of stomata	The wings fluttered up and down	1. Wings flutter up and down 2. Spread and fold in the plane
Lift/weight	Moderate	More	Less
Structural complexity	Simple structure but the complex manufacturing process	The simple structure can be completed by the mechanism design	The structure is complex and difficult to manufacture
Control the difficulty	The control is simple but the overall implementation is difficult	Control simply by controlling the flutter frequency	Control system complex wing deployment and closure in different states
Degree of difficulty in development	The principle is simple, but the realization is difficult due to the material and technology	Relatively simple has a similar case application	Difficult to achieve, the overall overweight mainly in the experimental stage

4. Trajectory Simulation

Path planning is a very important part of the autonomous flight system of the ornithopter, which enables the ornithopter to reach the target position from the starting point with the shortest path or time while avoiding obstacles. In order to reduce the energy consumption of cement-based ornithopters and improve their data acquisition efficiency, the Deep Reinf cement Learning (DRL) method is used to study the path planning strategy of ornithopters. Based on the Semi-Markov Process, discrete space modeling for data acquisition of ornithopters is completed. Semi-Markov-Option hierarchical reinforcement learning method and rainbow deep reinforcement learning algorithm are combined to make path planning strategy for ornithopters [7].

In the wireless sensor network, sensor nodes are randomly distributed in the region. SR is used to represent sensor nodes that need to be detected. It is assumed that there are N sensor nodes SR, that need to be collected in the region. The acquisition process of an ornithopter in a wireless sensor network[11].

Starting from the initial stop point, the ornithopter collects data from sensor nodes in the wireless sensor network. In the wireless sensor network, the ornithopter flies at a constant velocity of v and a fixed altitude of h. When the ornithopter reaches the communication range of the node, it will send an excitation signal to the node to wake up the node. After the node is woken up, it will conduct data transmission with the ornithopter, and send all the cached data to the ornithopter to indicate the point to complete detection and clear its own cache space. After visiting all nodes at least once, the ornithopter will return to the docking point to finish the task and wait for the next detection task. In the process of detection, if the maximum available energy max of the ornithopter is all consumed, it is also considered to return to the docking point to replace the battery.

$$\max = \frac{\mathrm{L_{total}}}{\mathrm{W_{total}}}' = W_{total} \leq W_{\max}$$

The communication diagram between the ornithopter and the sensor node is shown in Figure 3 below. The maximum communication distance of the node is r, and the communication distance of the ornithopter is ru (0 < r < ru). When the distance between the ornithopter and the node is less than r, the two parties can communicate. 9 is the included Angle between the ground horizontal line and the connection line of the ornithopter and node SRi, namely, the elevation Angle of communication between the ground node and the ornithopter. df is the flight distance projected on the horizontal plane of the ornithopter in the node communication range[14].

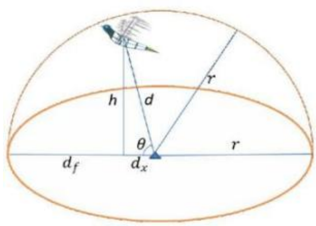


Figure 3. Communication model between ornithopter and sensor node

d, h, d_x and d_f are satisfiers (1) in Figure 3.

$$\begin{aligned} d^2 &= h^2 + d_x{}^2 \langle r^2 \\ d_x &= \sqrt{d^2 - h^2} \\ d_f &= r - d_x = r - \sqrt{d^2 - h^2} \end{aligned} \tag{1}$$

Obviously, when h is large, d_x is small and df is large, that is, the ornithopter needs to fly a larger distance in the horizontal direction. When h is small, dx is large and df is small, that is, the flight distance of the ornithopter in the horizontal direction is small. However, it is important to consider the height of obstacles on the ground and avoid collision in the real environment. Because the value of h largely depends on the specific communication environment between the ornithopter and the sensor node, there are different optimal values in different communication environments [8].

The flight energy consumption of the ornithopter, Wfly, is related to the flight distance and flight speed. W_{fly} is expressed as Equation (2).

$$W_{fly} = W_v \frac{D_f}{v} \tag{2}$$

In the Equation,

Wv--The energy expended by an ornithopter flying at speed V unit time

D_f--The total flight distance of an ornithopter during a detection mission.

The uplink data of the ornithopter consumes energy W_{upload} can be expressed as shown in Equation (3).

$$W_{upload} = \sum_{i=1}^{N} L_{SR_i} W_{ub} \tag{3}$$

In the Equation: W_{ub}-- The amount of energy used by a flapping-wing aircraft to transmit unit-size data.

The energy consumed by the ornithopter working in the air is represented by W_{stay} as shown in Equation (4).

$$W_{\text{stay}} = T_{\text{stay}} W_{st} = \frac{\sum_{i=1}^{N} L_{SR_i}}{P_{rec}} W_{st} \tag{4}$$

In the Equation:

T_{stay}--The amount of time an ornithopter is in the air.

W_{st}--The energy consumed per unit of time by an ornithopter in the air.

P_{rec}--Rate of detection by ornithopter.

W_{total} represents the total data consumption of an ornithopter in a data acquisition mission. The Wtotal can be obtained mainly depending on the flight distance of the ornithopter and the amount of data collected.

$$W_{\text{total}} = W_B + W_{fly} + W_{upload} + W_{stay} \tag{5}$$

To sum up, although the load of the equipment related to flight path planning is increased, the weight of the equipment is far less than that of the ornithopter by 0.5 kg [10]. Therefore, the addition of equipment related to flight path planning does not affect the flight of the ornithopter [9]. Through simulation, it can be seen that the shortest path detection time of an ornithopter based on flight path planning analysis is less than that without flight path planning[12].

After the flight path planning, the power consumption of the whole process of single air detection is 60%. However, the power consumption of a single air detection of the ornithopter without flight path planning is 80%. In comparison, the power consumption of a retract-planning ornithopter is 20% lower [10].

5. Simulation Performance Analysis Design

In order to verify the rationality of the design scheme, after the completion of each part of the scheme design, need to design related experiments, experiments to verify[13]. The experiment in this paper mainly includes the simulation and test of the performance analysis platform, the performance test and analysis of the bird-like flapping-wing robot prototype with different wings, the angle of attack, the relative incoming flow and the flapping frequency to the flapping-wing, influence analysis of aerodynamic force and flight control experiment of robot. Based on the mechanism and control system design of the flapping-wing robot simulation performance test platform introduced above, the simulation environment of the system needs to fit the reality. The simulation test environment built by the project team is mainly divided into the following parts: wind force of different degrees of demeanor, avoiding obstacles, as shown in Figure 4(a), figure 4(b). Of course, wind speeds are different at different altitudes and degrees, as shown in table 2.

(a) (b)

Fig.4(a)schematic diagram of wind resistance in Simulation; (b) simulation environment of wind resistance with obstacles

Table 2 wind speed at altitude for wind grades

Wind speed rating	10 meters high Average wind speed of 30 minutes(m/s)	30 meters high Average wind speed of 30 minutes(m/s)	50 meters high Average wind speed of 30 minutes(m/s)
1	4.1	5.1	5.6
2	5.1	5.9	6.4
3	5.6	5.9	6.4
4	6.0	7.0	7.5
5	6.4	7.4	8.0
6	7.4	8.2	8.8
7	9.4	11.0	11.9

The national average annual wind speed at 30m is 8.5 m/s, according to historical China Meteorological Administration data

The simulation test function, but in the process of the realization of the ornithopter exposed before the overall center of gravity, in the test, the process of easy to increase the vibration of the system. So put the motor flight control and other components in the ornithopter in the middle and rear position.

6. Conclusions

Based on Inventor software, the structure design and trajectory planning of flapping-wing aircraft were detailed by using bionic technology and simulating the principle of bird flapping-wing. A new type of bionic flapping-wing drive mechanism is proposed based on the comprehensive analysis of the bionic flapping-wing drive mechanism. The feasibility of the mechanism is verified by Inventor software modeling and kinematics simulation.

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(3) First-class course construction project" Electromechanical transmission control" research results

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