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Research Article

Design and Research of Dragonfly Robot under the Background of Artificial Intelligence

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Simulating the flight of dragonflies has always attracted scientists' interest. This paper studies the theory and method of the transmission mechanism of dragonfly robot, establishes the relationship function model between wing swing angle and geometric parameters, and designs a kind of gear and rod mechanism transmission chain, including a pair of wing angle turnover mechanism, so that the wings swing smoothly, no jam phenomenon occurs, and improves the lift ratio. In this paper, the dynamic principle of Bionic Flapping Wing robot was analyzed, and the design scheme of driving mechanism is put forward; the project realizes the three-dimensional design of robot parts, the virtual digital prototype and simulation, and 3D printing of the prototype robot. During the design and manufacture, the lightweight design and processing of the fuselage and wings are carried out to reduce its weight. The drive circuit and algorithm are designed with 8051 chip as the CPU; the balance and attitude control methods are proposed.

1. Introduction

Dragonfly is one of the most excellent flying creatures in nature. It can fly upside down, sideways, vertically, even glide, or hover in the air [1]. Dragonfly's special flying ability is attributed to its developed wing muscles and airbags. The wing muscles can quickly flap the wings and adjust the tilt angle. The air bag stores air, which can regulate body temperature and increase buoyancy [2]. Depending on its neural system to control the tilt angle of the wing and adapt to the flight speed and atmospheric pressure, it can not only generate upward lift but also produce forward or backward thrust to realize free flight [3]. The wings can vibrate 30 to 50 times per second and can fly at a speed of 9 meters per second.

People have been exploring the flying mechanism of dragonflies. FESTO company in Germany has developed a dragonfly named "bionic opter." Its length is more than 17 inches (about 43 cm), which is far larger than the real dragonfly. It can flap its wings 20 times per second, with a wingspan of 63 cm, a body length of 44 cm, and a weight of 175 g. Bionic opter can vibrate each wing individually and control the amplitude, frequency, and angle of attack of each wing to slow down and make sharp turns, accelerate, and retreat. In addition, lightweight design, carbon fiber, and foil materials are used to reduce the weight. Park and Yoon addressed four ornithopters ranging in wing span from 10 cm to 40 cm and in weight from 5 g to 45 g and consider that aspects of insect flight such as delayed stall and wake capture are essential at such small size [4]. Qi et al. took wind tunnel experiments on mav0701 micro flapping wing aircraft and studied the effects of wind speed, angle of attack, and flutter frequency on its aerodynamic characteristics [5]. Ho et al. reviewed the scaling laws and unsteady flow regime constraining both biological and man-made fliers and summarized vortex dominated unsteady aerodynamics follows [6]. Lehmann addressed that physical and analytical models of oscillating wings have demonstrated that a prominent vortex attached to the wing's leading edge augments lift production throughout the translational parts of the stroke cycle, whereas aerodynamic circulation due to wing rotation, and possibly momentum transfer due to a recovery of wake energy, may increase lift at the end of each half stroke [7].

Gallivan found to be important factors in a wing's performance from experiments at flapping frequencies from 0 to 4 Hz, at wind speeds from 0 to 6 m/s, and at angles of attack from -5° to +10° [8]. Adity and Malolan addressed modern flight control system (FCS) augment aircraft dynamics so pilots can more effectively accomplish complex missions [9]. Sane and Dickinson used a dynamically scaled model insect to measure the rotational forces produced by a flapping insect wing and found that steadily translating wing was rotated at a range of constant angular velocities, and the resulting aerodynamic forces were measured using a sensor attached to the base of the wing. They modified a standard quasi-steady model of insect flight to include rotational forces, translational forces, and the added mass inertia, which predicts the time course of force generation for several different patterns of flapping kinematics more accurately than a model based solely on translational force coefficients [10]. Srygley and Thomas trained red admiral butterflies, Vanessa atalanta, to fly freely to and from artificial flowers in a wind tunnel and used high-resolution, smoke-wire flow visualizations to obtain qualitative, high-speed digital images of the air flow around their wings. The results of these experiments seem to be no one "key" to insect flight; instead, insects rely on a wide array of aerodynamic mechanisms to take off, manoeuvre, maintain steady flight, and for landing [11]. Wang et al. proposed a bionic mechanical design of flexible wings on the mechanism of insect and small bird wings, and a conclusion is that the aspect ratio and rigidity of leading beam have effects on lift force; variety rigidity of leading beam and big aspect ratio are beneficial to the production of lift force by analyzing and studying experimentally [12]. The drawn conclusion is coaxial eight wings in the prototype design have advantage, which the total of lift coefficient of the coaxial eight flapping wings is larger than that of coaxial four flapping wings, and meanwhile an experiment platform for the micro air vehicle is set up. The experimental results show that the prototype of each index complies with the intended target [13]. When flying at low speed, the lift of the balance weight comes from both the downbeat motion and the swing up motion of the wing and is mainly contributed by the lift of the wing. The thrust to overcome body resistance mainly comes from the upward swing of the wing, which is contributed by the resistance of the wing. At medium speed, the lift mainly comes from downbeat motion, half of which is contributed by wing lift and half by wing resistance. The thrust mainly comes from the upward swing movement, which is also contributed by half of the wing lift and half of the wing resistance. In fast flight, the lift mainly comes from the downbeat motion, which is mainly contributed by the wing resistance. The thrust comes from the upward swing movement, which is mainly contributed by the wing lift. When hovering, the work done by the down shot and the swing up is the same. When flying forward, the downbeat does much more work than the swing up [14]. Shen et al. proposed principles of bionic robot redundant actuation, underactuated bionic principle, design of metamorphic structure, design of motion stability, design of high bearing weight ratio, and design of novel biomimetic materia1 [15].

Dragonflies seem to fly effortlessly and nimbly. The industrial research on dragonflies is just started; it will have a good application prospect in the field of disaster relief and safety investigation in narrow space and dangerous places. In this motivation, a dragonfly robot is studied, and a new structure is designed to imitate its maneuverability and concealment.

2. Motion Principle and Transmission Mechanism Design of Dragonfly Robot

2.1. Motion Principle. A pair of wings of a coaxial four flapping wing aircraft and two pairs of wings of a coaxial eight flapping wing aircraft are simulated under the same flapping angle, and after comparing their lift coefficient and drag coefficient, the crankshaft single crank double rocker mechanism is designed as the mechanical transmission mechanism of the prototype, and the lightweight design and material selection of the wing and fuselage are carried out. Through 3D printing processing, a four axis hinged four flapping wing prototype is developed.

The power source of the robot is the lifting force from four wings' motion. The wings are driven by gears and driven by the lift difference between up and down flapping. The body of dragonfly robot is similar to the vehicle bridge of automobile, which is the supporting structure and transmission support point of the whole robot. It needs to meet certain mechanical strength, including shear, compression, and vibration resistance. However, if the design strength coefficient is too high, the weight and load of the fuselage will be greatly increased, and the flight performance of the aircraft will be affected. Therefore, in the design process, quantitative design methods such as holes and slots should be added to the unstressed parts to reduce their own weight. The fuselage shell of the robot adopts streamline shape design to reduce the air resistance in flight.

2.2. Flight Transmission Structure and Wing Angle Adjustment Mechanism. Depending on gear and rod mechanism, the rotation motion of the motor is transformed into the up and down flapping of the wing, as well as the adjustment of the turning angle of the wing. The rotation of the motor changes speed through the first stage gear, then drives the gear rotate, and makes the eccentric connecting rod flickered. The other end of the connecting rod drives the wing rod to sway back and forth in a certain angle range, so the wing swings up and down in a certain angle range through the action of rod mechanism, and the dragonfly can gain its lift force. The flight transmission structure is shown in Figure 1.

In order to realize the robot flying backward, side flying, vertical flying, or hovering in the air, it is necessary to adjust the wing angle. The adjustment mechanism is rotated by micro stepping motor to drive the gear shaft to practice the wing angle adjustment, and the four coupled wing mechanisms control its flight attitude. The wing angle adjustment mechanism is shown in Figure 2.

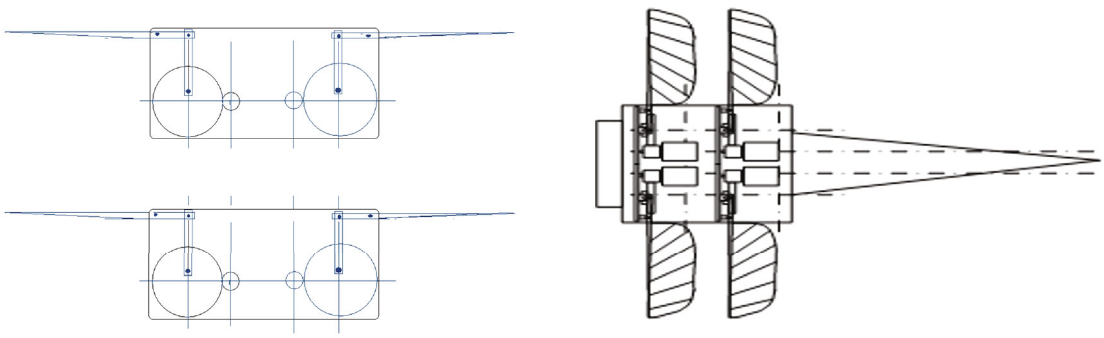


Figure 1: Flight transmission structure.

Figure 2: Wing angle adjustment mechanism.

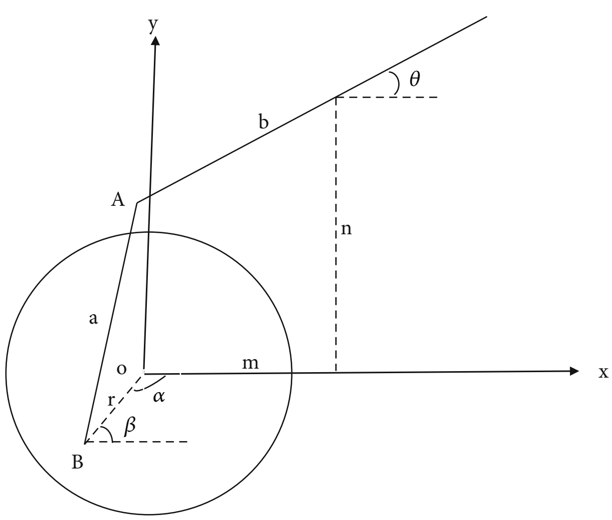


Figure 3: Geometric model of transmission mechanism.

3. Results and Discussion

Dragonfly's power comes from the motor. The motor changes speed through a pair of gears, and the four wings are driven by the rod mechanism. Each wing is independent of each other. The speed ratio of the first gear can be calculated as follows: I = the speed of the driving wheel/the speed of the driven wheel = the number of teeth of the driven wheel/the number of teeth of the driving wheel and the total speed ratio of many pairs of gears = the product of the speed ratio of each pair of gears. One end of the rod is connected with the wing swing rod through a shaft, and the other end is connected with an eccentric shaft on the gear. The rotating motion of the gear is transformed into the swing of the rod and the wing, as shown in Figure 3. The coordinate system is established with the gear center as the coordinate origin. Given that the length of rod AB is a, the length from wing swing rod to fulcrum is b, the eccentricity between rod end point B and gear center is r, the horizontal distance is m, and vertical distance is n from the wing swing rod fulcrum to gear center, namely, coordinate origin, respectively. The gear rotates clockwise, and the rotation angle is α. The relation function between the motion angle θ of wing swing bar and the mechanical parameters of transmission mechanism can be dressed as follows.

In Figure 3, the coordinates $A(x_A, y_A)$ and $B(x_B, y_B)$ of terminal points A and B of connecting rod are $A(n - b * \sin\theta, m - b * \cos\theta)$, $B(r * \sin\beta, r * \cos\beta)$, because $\beta + \alpha = 180^\circ$, so the coordinate $B(x_B, y_B)$ of point B is $B(r * \sin(180^\circ - \alpha), r * \cos(180^\circ - \alpha))$.

$$AB^2 = (x_A - x_B)^2 + (y_A - y_B)^2, \tag{1}$$

$$\begin{aligned} a^2 = {} & (n - b * \sin\theta - r * \sin(180^\circ - \alpha))^2 \\ & - (m - b * \cos\theta - r * \cos(180^\circ - \alpha))^2, \end{aligned} \tag{2}$$

$$\begin{aligned} a^2 = {} & m^2 + n^2 + b^2 + r^2 - 2b(n * \sin\theta + m * \cos\theta) \\ & - 2r(n * \sin(180^\circ - \alpha) + m * \cos(180^\circ - \alpha)) \\ & + 2rb(\sin(180^\circ - \alpha) * \sin\theta + \cos\theta * \cos(180^\circ - \alpha)). \end{aligned} \tag{3}$$

By simplifying equation (3), the following relation functions are obtained:

$$\begin{aligned} 2b(n \sin\theta + m \cos\theta - r \cos(180^\circ - \alpha - \theta)) = {} & m^2 + n^2 \\ & + b^2 + r^2 - a^2 - 2r(n * \sin(180^\circ - \alpha) \\ & + m * \cos(180^\circ - \alpha)). \end{aligned} \tag{4}$$

From the relation function of equation (4), it says that the motion angle θ of the wing swing rod is related to the four geometric parameters a, b, r, m, and n, and the locking situation will not occur if the sum of the two sides of the

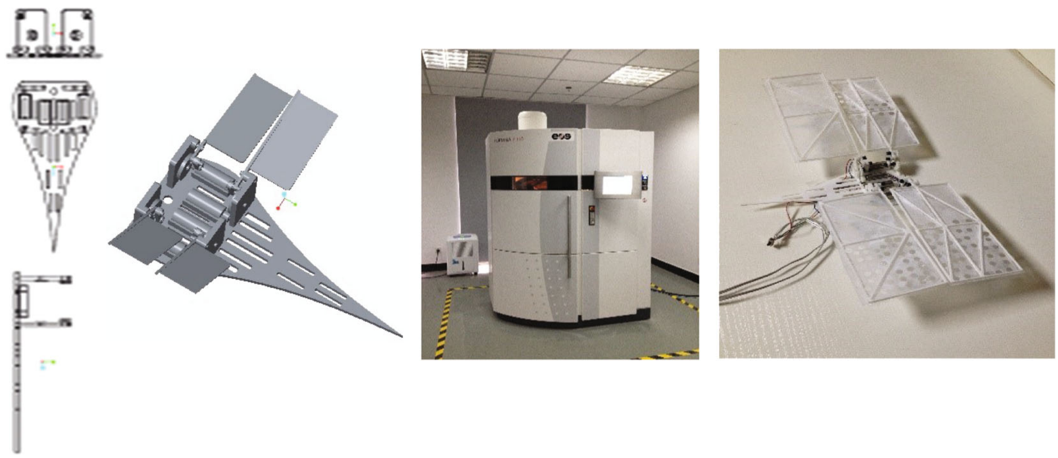


Figure 4: 3D modeling, virtual prototyping, and 3D printing prototype.

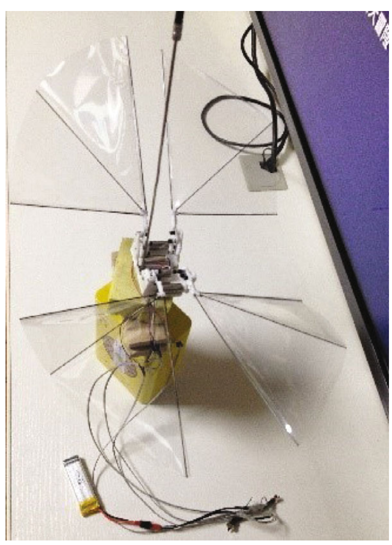


Figure 5: Lightweight robot.

triangle is greater than the third side. This relation function shows how to set parameters a, b, r, m, and n to get the maximum swing angle θ. The better transmission parameters have been obtained through full simulation analysis and calculation. By the process of design and simulation, the dimension parameters are obtained, namely, $a = 8$, $b = 6$, $r = 4.5$, $m = 8$, $n = 11$, and avoided deadlock. When the gear rotates in clockwise, the motion angle θ is stable within the range of 35 degrees on the x-axis and 45 degrees on the lower x-axis, and there is no locked phenomenon.

4. 3D Prototype Printing and Flight Driving Control Circuit of Dragonfly Robot

4.1. 3D Design of Parts and 3D Printing Assembly Debugging of 3D Prototype. All parts of the robot are modeled in prt data format with the PTC Pro/E software, and the assembly and simulation of three-dimensional virtual prototype are carried out to verify whether there are interference and over constraint problems in the transmission chain, so as to better adjust the design geometric dimensions and parameters of parts. After the simulation verification, the data is exported to stereolithography (∗.stl) format file that can be processed by 3D printer. After the 3D printing of the parts is carried out, they are assembled into a 3D printing prototype. The design, virtual prototype, and 3D printing prototype are shown in Figure 4.

In the debugging process, in order to improve the ratio value between its lift force and weight, further lightweight measures are taken for the fuselage and wings of the robot, for example, the auxiliary parts of the tail of the body are cut off, and the wings support the plastic film with carbon fiber rods, so as to reduce the weight of the robot itself. The area size of the plastic film wing has been adjusted in many times for making a reasonable balance between the frequency of the wing swing up and down and the output function of the motor. If the wing area is too large, the load on the wing when the wing swings up and down increases, and the motor speed slows down, which affects the flight performance of the robot; on the other hand, if the wing area is too small, the lift force of the wing is reduced when the wing swings up and down, although the motors make the speed of the robot increase, because the lift ratio decreases, so these factors will affect the flight performance of the robot. The speed of the robot increases, but the lift ratio decreases; also, these factors will affect the flight performance of the robot. The lightweight robot is shown in Figure 5.

In order to further reduce the air resistance in the process of wing upward swing, the wing angle adjustment mechanism in Figure 2 is added in the research process, so that the wing would be turned to be vertical to the arm of force in the process of upward swing and horizontal to the arm of force in the process of downward swing, so as to reduce the resistance, improve the efficiency of motor output power, and improve the wing swing frequency.

4.2. Drive and Control Circuit. For controlling flight gesture and keeping balance, the output power of each motor and the flight speed of each wing need be adjusted frequently. The control chip adopts 8051 microprocessor, and a PWM frequency converter is used to control the motor speed and

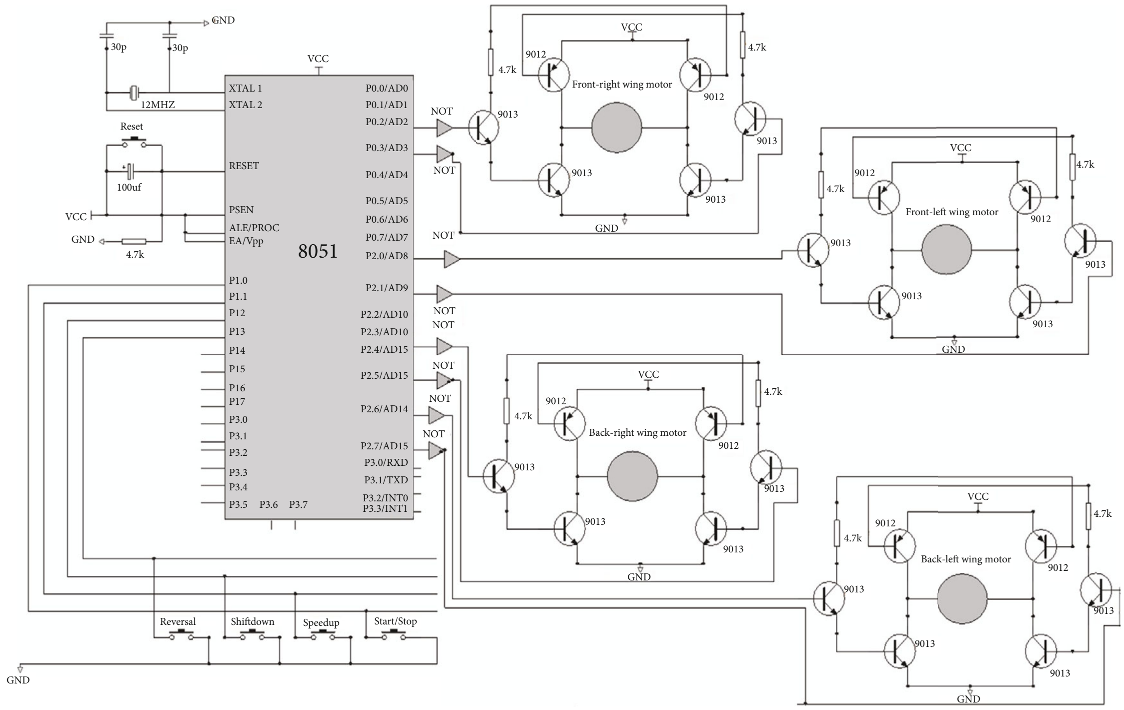


Figure 6: Drive and control circuit.

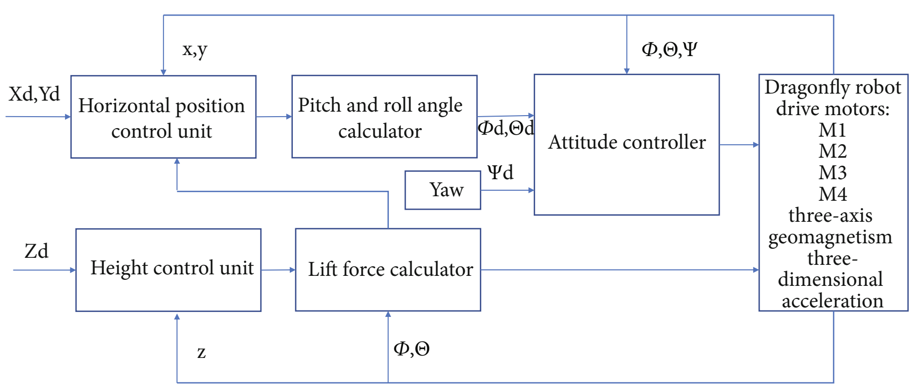
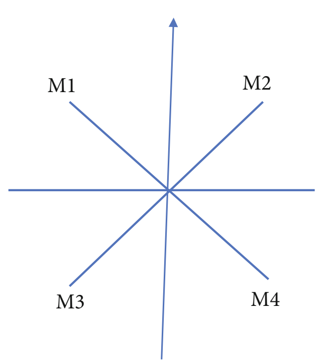


Figure 7: Gesture and balance control structure.



Control	M1	M2	M3	M4
Positive pitch	+	+	–	–
Anti pitch	–	–	+	+
Positive roll	–	+	–	+
Anti roll	+	–	+	–
Go ahead	+	–	–	+
Anti course	–	+	+	–
Rise	+	+	+	+
Drop	–	–	–	–

Figure 8: Drive motor arrangement and cooperative control.

output power by software; the bridge circuit is constructed by three pole tubes to control the motor forward and reverse. The drive and control circuit is shown in Figure 6. In the later stage, the balance and flight attitude of dragonfly were controlled by combining the data of external input equipment and gyroscope.

4.3. Gesture and Balance Control Algorithm. There are many dynamic models of aircraft, such as backstepping, LQ, and ADRC; their three basic flight parameters are pitch, roll, and yaw; the rotation speed of their motors is controlled to achieve lifting, hovering, and other actions. There are many controlled methods, including PID, segmented PID, fuzzy PID, adaptive PID, and neural network PID.

For the dragonfly robot, it needs to collaborative control four motors of four wings to realize its gesture and balance in lifting up and down, hovering, and roll. The collaboration among control four motors has more flexibility in angle control and agility in speed regulation. If the speed of one motor changes the counter torque, but the torque produced by the other three motors does not change, so the force balance will be break down. Meantime, the quad rotor not only rolls but also generates additional motion on the yaw. Perhaps paired control of motors is an optional strategy for resolving these problems.

The pitch, yaw, and roll angle are obtained by quaternion method from the three-axis angular velocity of gyroscope instrument. This is a fast solution. The drift compensation and depth calculation are obtained by combining the three-axis geomagnetism and three-dimensional acceleration. These data are fused together to obtain the air attitude of the dragonfly robot, which is presented by quaternion, Euler angle, matrix, and axis angle. Quaternions are used to preserve the attitude of the dragonfly robot, including rotation and orientation. After the quaternion is obtained, it will be converted into Euler angle and input into the attitude control algorithm. The details of gesture and balance control structure for the dragonfly robot can be seen in Figure 7.

The four drive motors are arranged as Figure 8, named X method, which are cooperative controlled every time.

Through PID, the motor PWM is adjusted to reduce the error between the expected attitude and the current attitude, and the complex actions such as hovering and route can be realized. The PID can be dressed as follows:

$$\begin{aligned} u(t) = Kp * [e(t) - e(t-1)] + Ki * e(t) \\ + Kd * [e(t) - 2 * e(t-1) + e(t-2)]. \end{aligned} \tag{5}$$

In equation (5), $u(t)$ is the control quantity given to the motor this time, and $e(t)$ is the error between the expected attitude and the measured attitude at the current moment. Turn on the motor to ensure that the attitude error is within 1° under strong vibration.

Using the current axis error $e(t)$, the previous axis error $e(t-1)$, the last axis error $e(t-2)$, and three sets Kp, Ki, and Kd of PID parameters, the flight of dragonfly robot is controlled, the control matrix is as follows:

$$\begin{vmatrix} Up(t) \\ Ut(t) \\ Uy(t) \end{vmatrix} = \begin{vmatrix} ep(t) - ep(t-1) & ep(t) & ep(t) - 2 * ep(t-1) + ep(t-2) \\ er(t) - er(t-1) & er(t) & er(t) - 2 * er(t-1) + er(t-1) \\ ey(t) - ey(t-1) & ey(t) & ey(t) - 2 * ey(t-1) + ey(t-2) \end{vmatrix} * \begin{vmatrix} Kp \\ Ki \\ Kd \end{vmatrix}. \tag{6}$$

In equation (6), up, ur, and uy are the control variables of each axis, ep, er, and ey are the attitude errors of each axis respectively. After obtaining the approximate proportional coefficient $K\omega$ between the motor speed and PWM duty cycle, the four duty cycles $U1$, $U2$, $U3$, and $U4$ are calculated.

These control parameters are input to the PWM software to drive four motors. The current dragonfly robot body design is a basic platform, which is used to debug the optimization control software for full real-time flight test.

5. Conclusion

At present, the 3D printing of dragonfly's mechanical and transmission structure design has been completed, and the debugging work of the robot is also in progress. At present, the project has encountered the first bottleneck. The original wing design is proved to be unable to meet the lift ratio. An optimization is carried out, including adjusting motor power, weight, and robot size. The current design is to increase the eccentricity of transmission gear to increase the wing range and the lift force.

Currently, the robot has been able to take off without load. If the motor volume is the same, the original design will be more feasible. Of course, there is a brief circuit design in software, but the complete program needs more flight data. In future, the control software will be improved to make gesture and balance control more cooperative by wings. Meanwhile, the hardware and site conditions need more sufficient support to provide effective data.

The difficulty of design also means higher performance. Compared with rotorcraft, small flapping wing aircraft has higher maneuverability and adaptability. In future, the fixed wing aircraft can be better used as investigation units in security work from large to important departments and from vehicle mounted UAV to make up for the lack of manual and monitor mobility.

Data Availability

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Conflicts of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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