# Implementation and Analysis of the Transmission Mechanism of Seagull Flapping Wing Aircraft

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## Abstract

**The purpose of this study was to design and analyze a biomimetic transmission mechanism of seagull flapping wing aircraft to simulate the unique flight skills of seagulls in flight and improve the maneuverability and stability of the aircraft. By delving into the biomechanical structure of the seagull, we developed a complex transmission system that mimics the movement of the seagull's wings. Using SolidWorks software for 3D modeling and computer simulation, we carried out detailed simulation and analysis of the mechanical motion of the aircraft in different flight states. The results show that we have successfully designed and implemented a biomimetic transmission mechanism, which can more naturally simulate the flight dynamics of seagull wings. After many practical tests and computer simulations, this transmission system has shown excellent performance, excellent stability and maneuverability, and is suitable for a variety of complex flight missions**

## Keywords

**Seagull Flapping Wing Aircraft; Transmission Mechanism; Bionics; Design.**

## 1. The Principle of Flight and Coordinate System of the Seagull Ornithopter

### 1.1 The Sport Mode of the Ornithopter

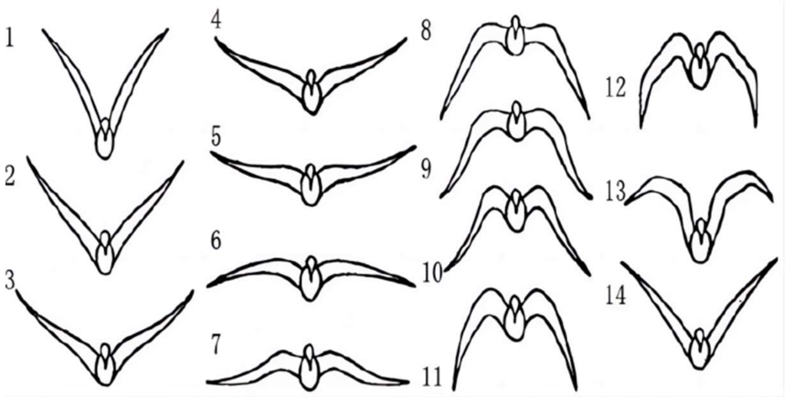


**Figure 1.** Changes in the curvature of the wings of birds

The movement pattern of the ornithopter is based on a design that mimics flying creatures in nature. Its core features include simulating the vibration of birds through their wings to generate lift. This movement of the wings drives the aircraft to generate lift and propulsion in the air, similar to the movement of the wings of a bird as it flies through the air. At the same time, through precise rudder control and attitude control, the flapping wing aircraft is able to adjust the angle and speed of the wings to precisely control the flight direction, altitude and speed, and the power system is the key to driving the wing vibration, which may use electric motors, compressed air or other forms of power. The integration of these systems makes the ornithopter an integrated engineering system that involves multiple disciplines such as mechanics, control systems, and aerodynamics to mimic and implement the complex principles of biological flight. Because the movement mode of bird wings is a complex three-dimensional movement, and even includes the expansion and contraction of wings in the upward fluttering stage, the bionic ornithopter can only simplify the wing movement of birds into a combination of vertical up and down fluttering and axial torsional movement of the wings, and the schematic diagram of the wing changes in the upper and lower fluttering stages of birds is shown in Figure 1.

Figure 1. shows the different forms of a bird's wings in a flapping cycle [1], which shows that the flapping of wings can be divided into four phases in a cycle:

(1) Downswing stage (1-6): This stage refers to the fluttering of the bird's wings from the highest point to the lowest point, in this stage the bird's wings gradually and fully unfold, in order to maximize the projection of the wings in the horizontal plane to produce high lift, and at the same time, the wings will also undergo a certain twist to produce the thrust required for the bird to fly forward.

(2) Bending phase (7-9): This phase occurs at the end of the wing flutter phase, when the outer wing bends relative to the inner wing at the lowest point of the wing flutter cycle, in order to minimize the generation of negative lift and prepare for the ascending stage. The bending phase occurs relatively quickly and occurs much less in time than in other stages.

(3) Ascending stage (10-12): This stage refers to the movement of the bird's wings from the lowest point to the highest point, and the area of the bird's wings to bear air in this stage is constantly decreasing, resulting in a decrease in the negative lift value and an increase in the net lift value. Since the wings still have a certain projection area, they are still subject to air resistance during the upward swoop phase.

(4) Flattening phase (13-14): Occurs at the end of the upward swoop stage, when the bird's wings are swooped up to the highest position, the outer wings are still stretched upward, the bending angle of the inner and outer wings slowly decreases, and the wingspan area reaches the maximum, ready to enter the next downward swoop stage.

It can be seen that when the wings of birds are swooped up, they will be accompanied by the deformation and folding of the wings, which is mainly because the wings produce negative lift when they pounce up, and birds reduce the negative lift force generated by reducing the wing area in this way.

## 1.2 The Flight Coordinate System of the Ornithopter

Several main coordinate systems of FWAV are defined [2], and the coordinate system of the bionic flapping wing aircraft is based on its center of mass, as defined in Figure 2. o is the center of motion of the ornithopter, the x-axis is parallel to the direction of movement of the ornithopter, the z-axis is perpendicular to the x-axis, and the y-axis is perpendicular to the plane xoz, and conforms to the right-hand rule.

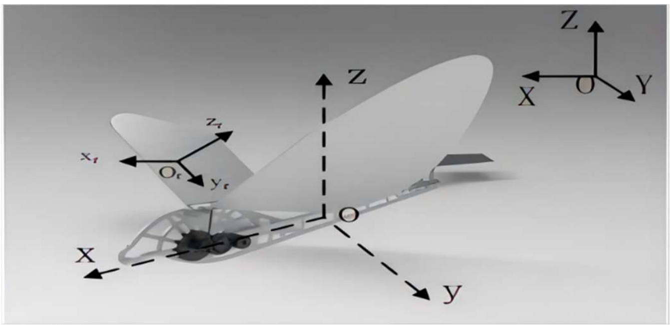


**Figure 2.** Definition of a coordinate system

Ground coordinate system OXYZ

OXYZ is the ground coordinate system, also known as the inertial coordinate system, the origin O is the center of mass of the ornithopter take-off, the OX axis is parallel to the horizontal plane, and the flight direction is positive, and vice versa; The vertical fuselage of the OZ axis is positive upward, and negative on the contrary; The OY axis is perpendicular to the other two axes and forms a right-hand coordinate system.

The body coordinate system oxyz

The origin o is the center of mass of the ornithopter; The ox is positive along the direction of flight and negative on the reverse side; oz perpendicular to the direction of flight and upward is positive, vice versa; The oy axis is perpendicular to the other two axes and forms a right-hand coordinate system.

Wing coordinate system oxryrzr

The origin of the coordinate system o is the aerodynamic center of the right wing of the flapping wing aircraft; The oxr axis coincides with the ornithopter flight direction; The oyr axis perpendicular to the right wing facing upwards is positive, and vice versa; The ozr axis is perpendicular to the other two axes and forms a right-hand coordinate system.

## 2. Seagull Mechanical Structure Design

### 2.1 Size Parameters of the Prototype of the Bionic Flapping Wing Robot

There is a certain relationship between the class-related size parameters and the motion parameters, which is called the scale effect [3]. The relationship is as follows:

Table 1 shows. In this paper, in the early stage of designing the prototype of the flapping wing aircraft, according to the experimental requirements, a simple reference is made for the parameters of the flapping wing aircraft, including the size of the size and the selection of materials, and then the parameters are modified according to the needs of the flight test.

**Table 1.** Relationship between parameters and mass of birds

| | Dimensional analysis | All birds | Birds except hummingbirds | hummingbird |
|---|---|---|---|---|
| wingspan | $\propto M^{0.33}$ | — | $1.17M^{0.39}$ | $2.24M^{0.53}$ |
| Wingarea | $\propto M^{0.67}$ | — | $0.16M^{0.72}$ | $0.69M^{1.04}$ |
| Wingload | $\propto M^{0.33}$ | — | $62.2M^{0.28}$ | $14.3M^{-0.04}$ |
| Aspect ratio | $\propto M^{0.00}$ | — | $8.56M^{0.06}$ | $7.28M^{0.02}$ |
| Minipower | $\propto M^{0.17}$ | $5.70M^{0.06}$ | — | — |
| Maxspeed | $\propto M^{0.17}$ | $15.4M^{1.10}$ | — | — |
| Frequency | $\propto M^{-0.33}$ | $3.87M^{-0.03}$ | $3.98M^{-0.27}$ | $1.32M^{-0.60}$ |

In this paper, when making the prototype of the bionic flapping wing robot, it can be seen from Table 1 above that the basic parameters of the aircraft, such as wingspan, wing area, and aspect ratio, are affected by the quality of the flapping wing robot itself. Referring to the size law in the above table, the mass of the flapping wing robot preliminarily designed in this paper is about 1000g, and the parameters of the bionic flapping wing robot prototype developed in this paper can be obtained from the above table 1 as follows:

wingspan $b$:

$$b = 1.17m^{0.39} = 1.17 \cdot 1^{0.39} = 1.17(m) \tag{1}$$

Wing area $S$:

$$S = 0.16m^{0.72} = 0.16 \cdot 1^{0.72} = 0.16(m^2) \tag{2}$$

As the most important part, the size of the wing directly affects the lift of the prototype, and the lift generated by the wing is proportional to the wingspan area.

Aspect ratio $AR$:

$$AR = 8.56m^{0.06} = 8.56 \cdot 1^{0.06} = 8.56 \tag{3}$$

The influence of the aspect ratio of the bionic flapping wing robot on its flight is reflected in the attitude, that is, the flexibility and maneuverability of the flight, and the aspect ratio and maneuverability of the flapping wing robot are negatively correlated. However, there is a positive correlation between aspect ratio and the lift generated by the wing, that is, the flapping wing robot with a large aspect ratio has greater lift but reduced mobility, which is similar to large birds in nature.

flutter frequency $f$:

$$f = 3.98m^{-0.27} = 3.98 \cdot 1^{-0.27} = 3.98(H_Z) \tag{4}$$

The flapping frequency is directly related to the lift of the flapping wing aircraft, in a certain range, the lift generated by the wing is proportional to the flapping frequency, compared with the birds in nature, the smaller the bird fluttering frequency, the slower the opposite. However, for flexible wings, too high fluttering frequency will reduce the generated lift, so it is necessary to consider the fluttering frequency of the wing from the aspects of mass and wing rigidity when making the prototype of the bionic flapping wing robot.

Compared with birds in nature, the wing flapping amplitude is reduced in two ways due to the negative lift generated during the upward flutter stage: one is to shrink the wings and reduce the wingspan area; The second is to reduce the upward flutter stroke, and the basic highest point is located above the horizontal plane to complete the upward fluttering action. For the current ornithopter production, either a retractable wing or a reduction of the upswing stroke is used, and this paper uses the reduction of the upswing stroke, that is, the maximum possible reduction of the generation of negative lift.

## 2.2 The Design of the Transmission Mechanism of the Seagull Flapping Wing Robot

Based on SolidWorks, the transmission structure of the seagull flapping wing robot is designed, and the specific three-dimensional modeling is shown in Figure 3, the auxiliary gear B and the steel shaft of 2 mm are directly driven by the brushless motor drive gear A, the brass gear C on the steel shaft drives the drive gear D to rotate, the wing of the flapping wing aircraft is connected to the joystick of the driving gear D, and the up and down fluttering of the wing is controlled by the up-and-down swing of the joystick.

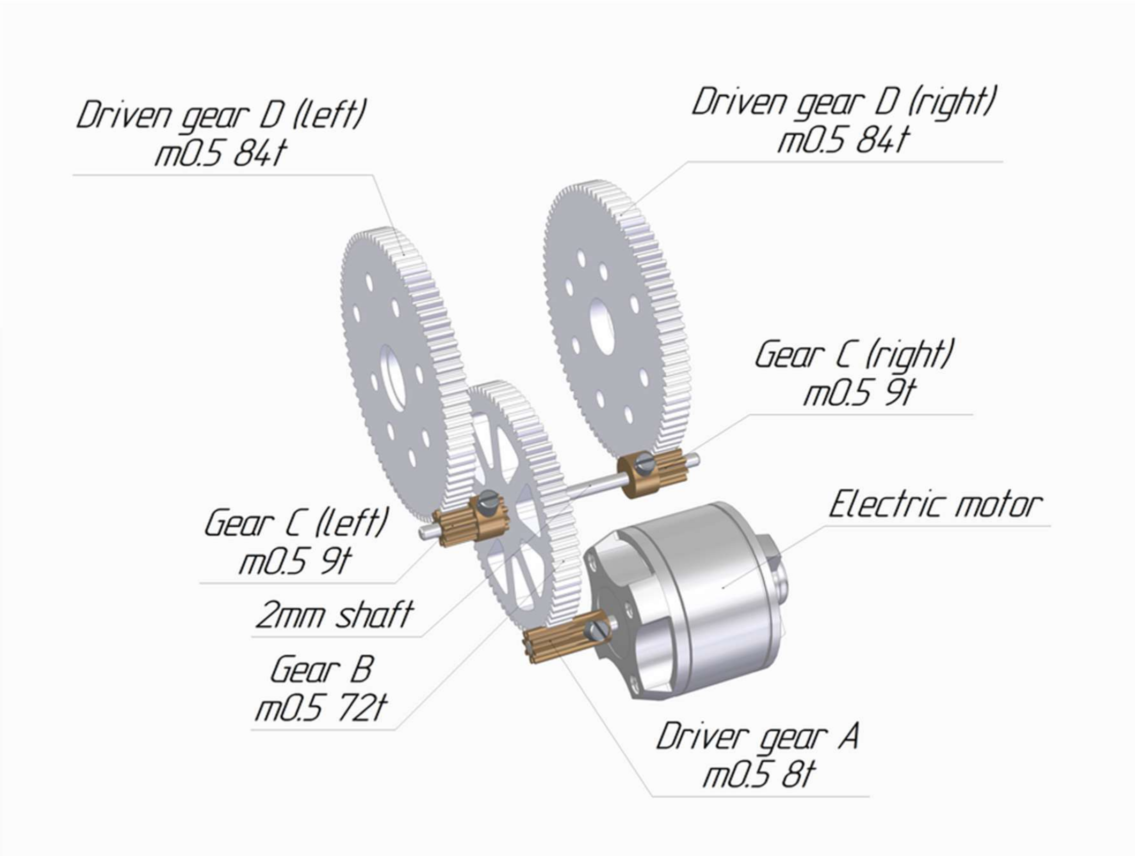


**Figure 3.** Modeling diagram of the ornithopter transmission mechanism

The flap frequency of the wings designed in this project is 5-7 times per second, gear A + gear B, the transmission ratio is 8:72, and gear C + gear D, the transmission ratio is 9:84. The driven gear A is mounted on the motor shaft. The left gear B and the right gear C are rigidly mounted on the shaft. As a result, they have the same rotational speed. Through the application of a two-stage gear reducer, the flapping wing robot can achieve low-speed and high-torque flapping wing movement driven by a high-speed motor, providing lift and thrust while maintaining a stable and controllable flight state. Such applications can improve the efficiency and performance of the aircraft while ensuring its safe and reliable operation.

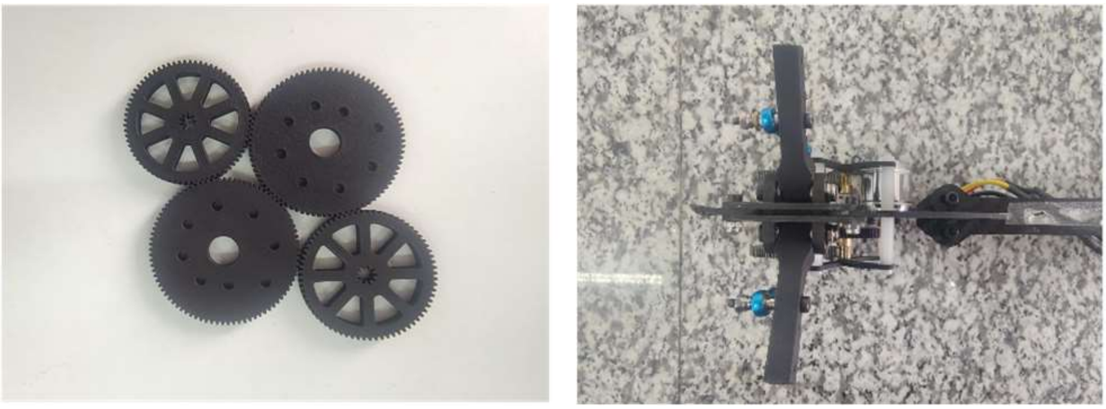
The transmission ratio of the reduction gearbox is:

$$i=(\text{Drive gear B}/\text{Drive gear A})*(\text{Transmission gear }D/\text{Drive gear C}) \tag{5}$$

The reduction ratio is calculated to be . The final total reduction ratio is 1:84.

So, when the motor is powered by a lithium battery with a rated voltage of 7.4V and a capacity of 800mAh, the output gear A from the motor rotates 31080 revolutions per minute or 31080/60 = 518 revolutions per second. From the total reduction ratio, the speed of the transmission gear D can be found, 518 / 84 = 6.16 revolutions per second.

Based on the above-mentioned reduction ratios, it is considered that the transmission mechanism of the ornithopter requires a material with a number of characteristics, including light weight, wear resistance, high strength, easy processing, heat resistance and chemical stability. In this case, nylon, as a synthetic polymer material, is undoubtedly the best choice, and the nylon 3D printing used in this paper as the transmission gear of the seagull ornithopter is shown in Figure 4(a). First of all, nylon, with its lightweight characteristics, helps to reduce the overall weight and improve the maneuverability of the aircraft. Secondly, nylon has good wear resistance, can withstand frequent mechanical movements without being easily damaged, and ensures the reliable operation of the mechanism for a long time. At the same time, the nylon material itself has high strength, which can withstand the stress caused by the movement of the wings and maintain the stability of the structure. Its ease of processing also makes it suitable for the manufacture of complex transmission structures to meet the needs of various wing movements. Finally, nylon has good heat resistance and chemical stability over a range of temperatures, allowing it to maintain stability during mechanical movements and in different environments. Considering these requirements and advantages, nylon material shows excellent applicability in ornithopter transmission mechanisms. The effect of 3D printing and repairing the mechanism of integrated printing is is shown in Figure 4(b).



(a) (b)

**Figure 4.** Seagull bionic ornithopter transmission mechanism physical drawing

### 2.3 The Design of the Tail Drive of the Seagull Flapping Wing Robot

Based on SolidWorks, the tail drive structure of the bionic flapping wing robot was designed, as shown in Figure 5. The tail drive structure is used to control the rotation of the tail fin, thereby controlling the attitude of the flapping wing robot. The existing tail drive structure has two kinds of single degree of freedom and double degree of freedom, and the single degree of freedom drive structure has only one yaw servo, which can only control the yaw motion of the flapping wing robot, but can not control the pitching motion of the flapping wing robot, so its flexibility is greatly reduced. However, the dual-degree-of-freedom drive structure has two servos, yaw servo and pitch servo, which can not only control the yaw motion of the flapping wing robot, but also control the pitching motion of the flapping wing robot, which effectively solves the problem of low degree of freedom of the single-degree-of-freedom drive structure.

**Figure 5.** Physical diagram of tail drive structure

In this tail drive, the pitch servo is connected to the yaw servo plate by means of a servo lever, which is directly attached to the yaw servo plate and the tail is connected to the yaw servo through a tail connector. The yaw servo fixed plate is driven by the servo lever to control the up and down movement of the tail, so as to realize the rotation of the pitching servo. Because the yaw servo is directly connected to the tail connector, the rotation of the yaw servo can directly control the left and right movement of the tail.

## 2.4 Wing Structure Design of Seagull Flapping Wing Robot

As one of the most important parts of the bionic flapping wing robot, that is, the core part of the structure of the bionic flapping wing robot, during the flight, while ensuring lightweight, it is necessary to take into account both lift and thrust, so the choice of wing shape will directly affect the thrust, lift and drag of the ornithopter during flight, as well as its stability and operational performance. Different flapping wing shapes have their specific flight performance [4], such as long wing shapes suitable for high lift requirements, and narrow wing shapes for high-speed flights; The wide wing shape improves stability, and the narrow wing increases maneuverability; The streamlined airfoil shape reduces drag, and the asymmetrical airfoil shape can cause aerodynamic instability. In the design of bionic flapping wing robots, it is necessary to take into account the task requirements and aerodynamic efficiency, and it is important to optimize the shape of the wing.

Combined with the design requirements, the flapping wing robot designed in this paper requires a large lift, and the fuselage material may be heavier, so in order to avoid the need to reduce the weight of the fuselage in the future, the long wing shape is selected as the wing shape [7] to obtain a large lift. The 3D model of the wing section is shown in Figure 6 below:

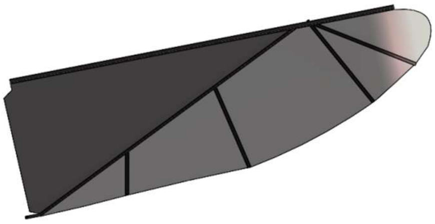


**Figure 6.** Wing model diagram

The performance of the flexible wing in terms of aerodynamic lift and thrust is significantly better than that of the non-flexible wing [6], and the experimental results are shown in Figure 7 below.

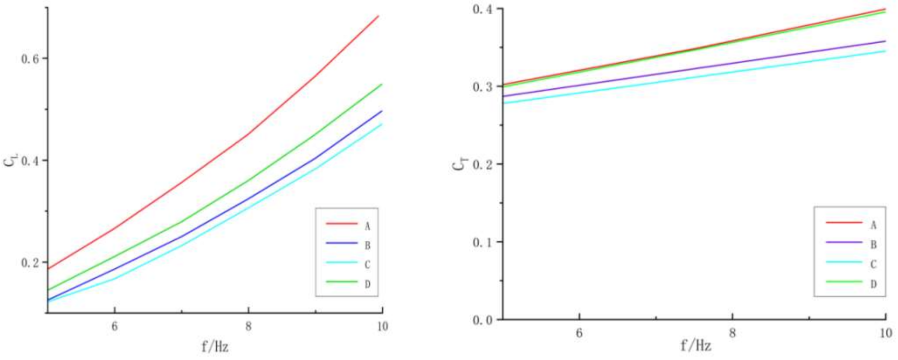


**Figure 7.** Effect of different airfoil shapes on thrust (left) and lift (right).

## 2.5 Hardware Design of Control Circuit of Seagull Flapping Wing Robot

The control system is the core part of the entire Seagull ornithopter, and should include the following functions: the control system needs to be able to perceive and adjust the attitude of the ornithopter robot in real time, including roll, pitch and yaw angle. The control system should be able to plan the flight path according to the mission requirements and ensure a smooth flight of the ornithopter. According to different tasks, the control system may need to support multiple modes switching, such as lifting, left and right, forward and backward and other motion modes. During the execution of the operation task, the control system can obtain the attitude information of the seagull flapping wing robot in time, and adjust the attitude to ensure the stability of the flight. The control system can obtain a more accurate state estimate by fusing data from multiple sensors. The control system usually needs to communicate with the ground station to receive, send control instructions and transmit real-time data. The structure diagram of the control system designed in this paper is shown in Figure 8.

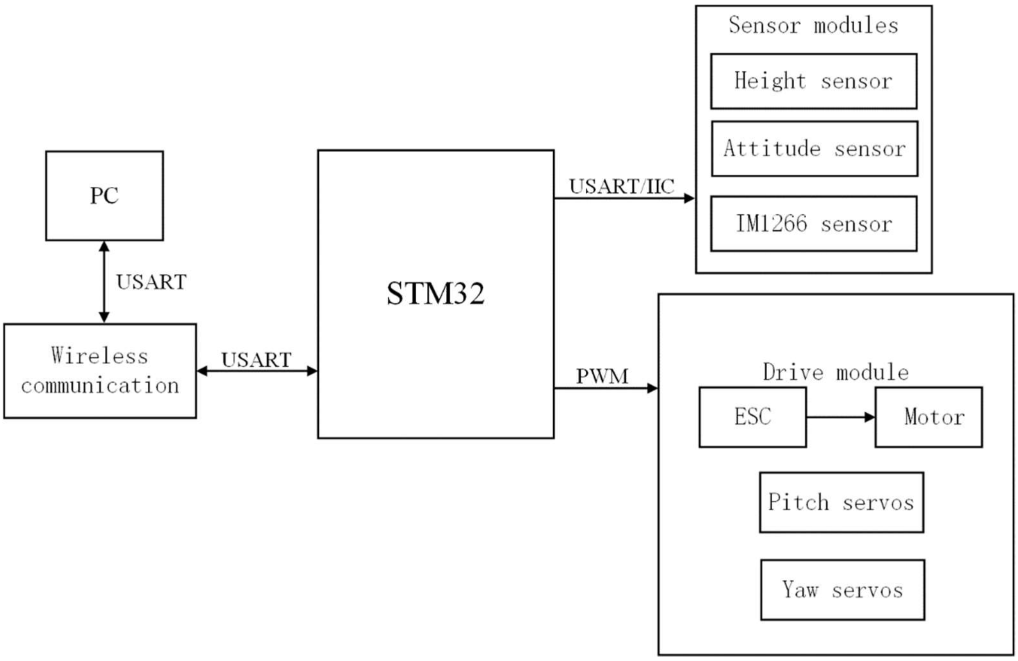


**Figure 8.** control system structure diagram

Based on the control system structure diagram of Figure 8, the designed system controller is composed of STM32F407VET6 single-chip microcomputer, which plays a major control role in the system as the core of the overall system; JY901B attitude sensor module is used as the attitude data measurement module of this platform; IM1266 AC and DC voltage, current, power and electric energy metering module is used as the current, voltage and power measurement module of this platform; The collected data is transmitted through the serial port (USART) of the STM32 microcontroller, and transmitted to the host computer through the wireless data transmission ATK-MW1268D module, so as to achieve better control of the solar bionic flapping wing robot.

## 2.6 Outdoor Flight Experiment of a Seagull Flapping Wing Robot

In order to ensure that the seagull flapping wing robot designed in this project can fly normally, outdoor flight experiments are also carried out in this project. The main purpose of outdoor flight is to test the flight performance of the flight platform and ensure that the Seagull flapping wing robot can continue to fly stably. Figure 9 shows an outdoor flight experiment of a bionic flapping wing robot.

**Figure 9.** Outdoor flight experiment of the bionic flapping wing robot

The airflow of the site is relatively stable, the site range is large, and it is an excellent experimental site for the test of the fast steering performance of the seagull flapping wing robot. After many tests, it was verified that the bionic flapping wing robot test platform had good performance and could take off smoothly. Climb quickly, turn in the air, hover high in the air, and finally land safely.

## 3. Conclusion

When studying the design and implementation of the mechanical structure of the seagull's flapping wing aircraft, we deeply explored the principles of biomimetics and tried to simulate the unique flight mode of the seagull. By exploring the flapping mechanism, material selection and technical challenges, we have taken a crucial step towards the realization of a bionic flying vehicle. The design of the Seagull drive is not only a technical challenge, but also a test of human creativity and engineering ingenuity. This process involves the intersection of multiple disciplines and requires engineers and scientists to work together to achieve a simulation of the seagull's flight characteristics. Despite the challenges, we believe that the research of this biomimetic aircraft will bring new breakthroughs to future aviation technology, not only to provide the possibility of aircraft performance and efficiency, but also to open up a new path for the development of the field of biomimicry. By imitating nature, we have explored many new technological ideas, and we look forward to bringing greater value to human society in the practical application of these technologies.

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