Design and Development of Flapping Wing UAV

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Abstract - *Flapping wing air vehicles are unmanned miniature aircraft's that draw inspiration from birds, bats and insects. They utilize continuous flapping wing motion to generate aerodynamic forces and moments. The fluid structure interaction analysis of biological and artificial flapping flyers is extremely complicated thus an efficient unsteady aerodynamic model is required in such time consuming problems as optimal flapping wing simulation. This project deals with designing a flapping wing air vehicle which includes applying inertial impulsive force to UAV in such a way that the flapping wing air vehicle reaches almost constant flight speed after removing the initial impulsive forces .The flow dynamics are different of the flapping wing air vehicles with that of the fixed wing UAV and this project deals with the utilization of the flapping wing in the UAV to overcome the challenges faced by a fixed wing UAV like maneuverability in remote areas, sound produced and identification during mission. Structural and aerodynamic characteristics of a bird in flight offer benefits over typical propeller or rotor driven unmanned air vehicle (UAV). Hence this study deals with the designing of an flapping wing UAV to overcome these drawbacks of fixed wing UAV.*
***Keywords**: Flapping Wing UAV, Radio Control, Micro Electro Mechanical System, Smart Composite Micro Structures*

I INTRODUCTION

Image in painting is a method for repairing damaged pictures or removing unnecessary elements from pictures. It recovers the missing or corrupted parts of an image so that the reconstructed image looks natural. In real world, many people need a system to recover damaged photographs, designs, drawings, artworks etc. damage may be due to various reasons like scratches, overlaid text or graphics etc.

This system could enhance and return a good looking photograph using a technique called image in painting. Image in painting modify and fill the missing area in an image inan undetectable way, by an observer not familiar with the original image. The technique can be used to reconstruct image damage due to dirt, scratches, overlaid text etc.

Some images contain mixed text-picture-graphic regions in which text characters are printed in an image. Detecting and recognizing these characters can be very important, and removing these is important in the context of removing indirect advertisements, and for aesthetic reasons. There are many applications of image in painting ranging from restoration of photographs, films, removal of occlusions such as text, subtitle, logos, stamps, scratches, red eye removal etc.

Paper is organized as follows. Section II describes automatic text detection using morphological operations, connected component analysis and set of selection or rejection criteria. The flow diagram represents the step of the algorithm. After detection of text, how text region is filled using an In painting technique that is given in Section III. Section IV presents experimental results showing results of images tested. Finally, Section V presents conclusion.

II LITERATURE STUDY

The theory of aerodynamics is the culmination of many individuals . It probably began with prehistoric man's desire to copy the actions of the bird and fly through the air. Arisototle conceived the notion that air has weight and Archimedes law of floating bodies formed the a basic principle of lighter-than-air vehicles .In the years around 1500 one man Leonardo da vinci foresaw the same shape of things to come. .Through his avid studies of bird flight came the principles of design that influenced many other scientists to work on ornithopters. Da vinci correctly concluded that it was the movement of wing relative to air and the resulting reaction that produces the lift necessary to fly. As a result of these studies, he designed several ornithopters - machines that were intended to copy bird's wing –the muscle power being supplied by man .But these designs did not leave the drawing board. The first flying machine that carried a man did not imitate a bird .instead it was based on the lighter-than-air principle and took the form of a large hot-air balloon.

Constructed by the two Montgolfier brothers from France, Although ballooning thereafter became a popular time, man was at the mercy of the winds and could not fly where he willed.

Sir George Cayley of England (1773-1857) is generally recognized as the father of modern aerodynamics .He understood the basic forces acting on a wing and built a glider with a wing and a tail unit which flew successfully. During late 1800's a number of inventors tried to use a steam engine to power their airplanes and had little success. Meanwhile, towards the end of the nineteenth century , a German named Otto lilienthal was successfully flying in gliders of his own design. Lilienthal proved the concept of heavier-than-air flight. Today these form of flying, now called hand gliding , is enjoying a substantial come back.

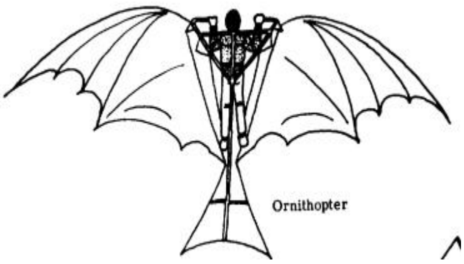
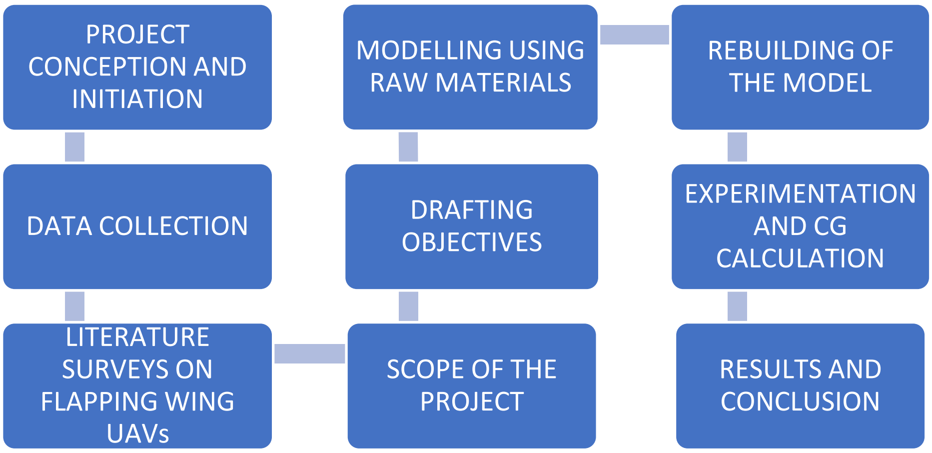


Figure 1.1 (a): Ornithopter

III METHODOLOGY



IV TECHNICAL DETAILS

Natural flyers use their wings as a lift-generating mechanism to stay aloft. One of the wing kinematics is clap-and-flapping. This technique suggests that wings are slapped together then flung apart at the end of each stoke. As a result, a bound vortex is formed on each wing edge, which remains attached until the next stroke, thus inducing circulation on the wing, creating a pressure differential and encouraging high values of lift. Other unsteady aerodynamic mechanisms, such as wing leading vertex and delayed stall , wing rotation, and wake capture, also contribute to lift generation in FW-UAVs. The first insect-sized FW-UAV invented was named Harvard Robobee. The high speed, highly articulated mechanisms that are necessary to replicate an insect-like wing flapping motion exists on a scale that is between micro electro mechanical systems (MEMS) and "macro" devices . Hence, a "meso" scale rapid fabrication method, the so-called smart composite microstructures (SCMs), were used to fabricate the Robobee. The flapping wing aircraft which will produce lift and thrust by the flapping mechanism. Using Bio-mimic various Ornithopter, designs have been suggested for civil and military applications especially for the purpose of surveillance. In this paper, the highly aerodynamic design for flapping wing UAV with advanced specifications have been created.

The flapping wing UAV made which can be used for surveillance or reconnaissance of a particular target and also for a specific environment without its own consciousness. The Ornithopter uses battery power, gear mechanism, which enables to increase the number of flaps. We are bringing down the specifications of various birds and trying it to convert it into perfect real time mechanism. As of the first initiative, the basic and operating principles of flight have been studied in order to understand the flapping mechanism.

- For an airplane/ bird to stay at a constant height, Lift force upwards = Weight force downwards
- For an airplane/bird to stay at a constant speed, Thrust force forwards = opposing force of Drag

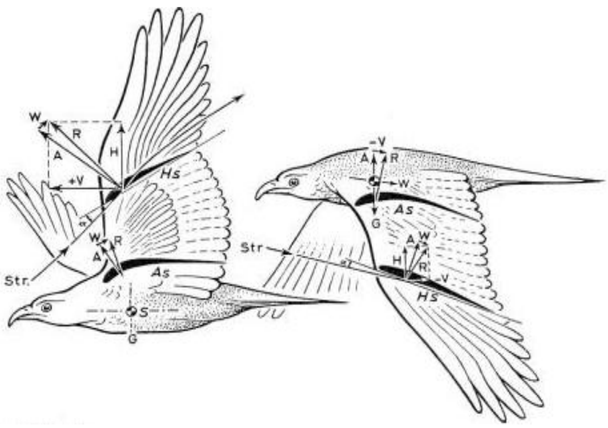


Figure 1.2: Flight Action of a Flapping Wing UAV

V MECHANICAL DESIGN

Statistically, birds are all born with complex and special bone structure and muscular system, which endows their wings with more than ten DOF for each wing. They can on the one hand perform the basic flapping motion when flying, and on the other hand are able to deliberately adjust their muscles and feather to change their morphology, thus to maneuver and to change direction and attitudes at the same time. And that's why birds are superior in deforming their wings and have remarkable flying performance. At the time when we first get started with developing our FW-UAV prototype, considering At the time when we first get started with developing our FW-UAV prototype, considering that the power that can be generated by the current MEMS technology, artificial chemical muscle and piezoelectric actuator is quite limited, which have been used by other scientists in their researches in the making of their ornithopters. we finally decided to use the more traditional means to drive the whole system, i.e. to use the more popular and mature technology, motor and mechanical transmission mechanism, to produce the required power and to achieve the payload of more than 100 grams. Since the schematic of these kind are mostly bulky, so in order to reduce weight and at the same time just to focus on exploring the inherent working principle of flapping flight, we simplified the motion of bird's wings by adopting only one degree of freedom, that is, we made the wings of our prototype can only flap ups-and-downs. The flapping motion of the two wings are known as the planar flapping with which the wing endpoints have only planar trajectory, without considering the twisting and folding motion of real birds' wings and without the typical spatial motion and adjustment. After determining the final arrangement of aerodynamic layout, transmission chain and methods to adjust our prototype's attitude, we finished the designing and assembling process of our FW-UAV prototype.

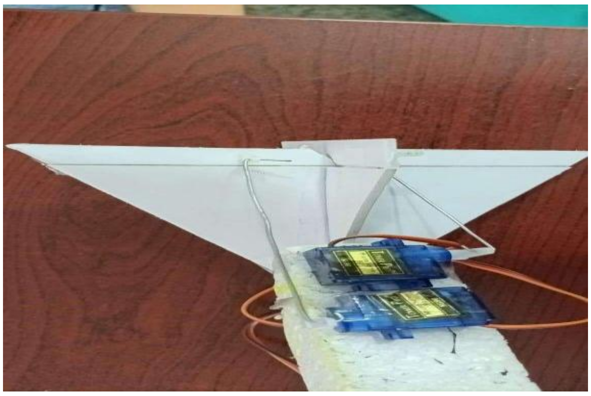


Figure 5.1: Tail Controlled by the Servos

There are 3 DOFs in total for this prototype. One is particularly used for the generation of flapping motion, of which the power is originated from the brushless motor, and the other two are for the adjustment movement of the pitch angle and roll angle of the tail provided by two servo motors mounted in the tail part, which will further directly affect the attitude of the body during flight. The 3D model of the prototype's flapping mechanism and tail attitude adjustment mechanism we can see that the whole flapping system is comprised of brushless motor, mechanical transmission mechanism, spatial crank rocker mechanism and the wings. The movement and power will be transmitted in the following way: firstly we remotely control the rotational speed of the brushless motor, and the double reduction gear unit will slow down the revolving speed and at the same time increase torque acted on the spatial crank rocker mechanism. The ball head tension rod connecting the crank and the wing rocker rod will transform the rotational motion of the crank to be the reciprocating swing of the wings. The rocker that swings to and fro acts as the radius and humerus of birds' wings. When the rocker swings, the wings flap ups-and-downs

The wing surface is covered with a kind of cloth membrane, which are usually used to make kites. When flapping, the wing interacts with the air, and the air then will be pushed backward, producing a certain amount of thrust and lift. On each side of the wing, we glued spars (see as Figure 5.3) that are used to strengthen the wing plane. The function of these spars mounted on the wing surface play a quite important role in generating aerodynamic forces, both their amplitude and direction, known as the wing flexibility determines the efficiency of flapping aerodynamics.

On the other hand, from the 3D model of the tail part we can see that the tail has the same plane structure as the wings. It also use the same kind of membrane cloth as its surface, and use two servo motors to adjust the movement of the tail part. The motion of the two servos is transmitted to the tail by using two parallelogram mechanisms. Among which servo 1 is used to control the pitch motion of the tail plane, which results in the tail revolves around axis 1 And servo 2 is used to control the roll motion of the tail plane, which will result in the tail revolves around axis 2, which is also the output axis of servo 2. While the wings of the FAV are responsible for generating thrust and lift, the empennage is then mainly in charge of generating the pitch torque and yaw torque relative to the center of body mass. The principle of the generation of these torques is that when the tail surface are applied with wind and air, the forces generated on the tail will produce a torque relative to the mass center of the body. And these torques will in turn effect the attitude and direction of the flight trajectory and the attitude of the body. The flapping frequency of the wings is directly controlled by adjusting the rotational speed of the motor, the requiring value is about 3~7 Hz. And the flapping amplitude and stroke range is fixed in our model, which is about –11°~45°.

The material of the main body is mostly balsa wood, which is cut from a large and complete sheet of balsa wood. The main balsa wood body frame is used to support and mount all other parts. Speaking of polythene sheet covered on the wing surface, of which the thickness and softness is of great significance.

We've tried various clothes of different stiffness, and we found that although mostly they are capable of generating enough lift and propulsion for flight, relatively, the kind that are thin and soft have better performance. The spars glued to the wings (see as Figure 5.3) together with the wing cloth, they change and determine the flexibility of the whole wing. After conducting many times of experiments, we choose the layout form as shown in Figure 5.3. What need to be stressed here is that the layout that we are using now is just the result of experience, and we still haven't thoroughly research about this. But we believe the wing flexibility problem is a rather complicated and deterministic one, and we will try to do more in-depth study in this aspect in the near future.

What needs to be emphasized is that the flapping mechanism design is the most difficult and important part. After many times of trials and modifications, we came to the conclusion that the selection of motor and gear reduction units and their combinations are of decisive importance for the problem whether the FAV will fly. We choose the appropriate motor by computing the maximum required power output according to the intended maximum weight and payload and the specified flapping frequency. And then compute the suitable reduction ratio and the battery voltage according to the required torque needed to drive the spatial crank and rocker mechanism. Last but not the least, the position of the mass center of the whole body is also quite important, which will directly determine the stability of the prototype when flying. Since when flapping, aerodynamic forces generated on the wings surfaces and tail surface is changing all the time, both the working point and the direction. So the torques of these forces relative to the center of body mass is also changing. How to make these two torques to equilibrate is then become a problem how to arrange components' positions, especially those bulky ones. Our experience is that to simplify the prototype as a fixed wing airplane with a certain anhedral, since the FAV has a larger positive extreme position than negative extreme position. And then we can use the simplified analysis method that the resultant aerodynamic forces generated in wings are roughly located in the position about one third of the chord length away from the leading edge. We should guarantee that the working point of this force is closer to the prototype's head then the center of body mass (CM), and is higher than CM along z axis, while the CM can be obtained by using tools of any 3D designing software. Our experience demonstrate that this simplification idea is quite useful. However, there are still quite a lot of trivial details and factors that will make the result not so desirable.

Figure 5.2: Gear Assembly

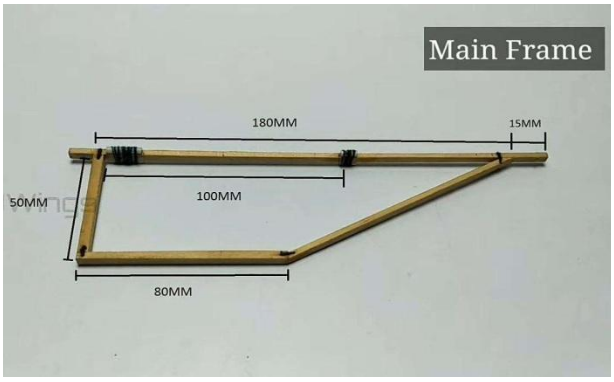


Figure 5.3: Main Frame

VI KINEMATICS

Since we adopted the scheme that the left and right wings are sharing the same power resource and using the same pair of transmission mechanism, so the wing flapping motion of each side is completely symmetrical. Which means, in any time, they both have the exact opposite and antisymmetrical angular position and angular velocity. Meanwhile, in one cycle the flapping motion of the up-stroke and down-stroke is also antisymmetrical, for each of them accounting for half the time of the whole flapping period, and for wings of each side it has opposite characteristics at the same position of down stroke and up stroke. Figure5.5 is the schematic diagram of the flapping mechanism.

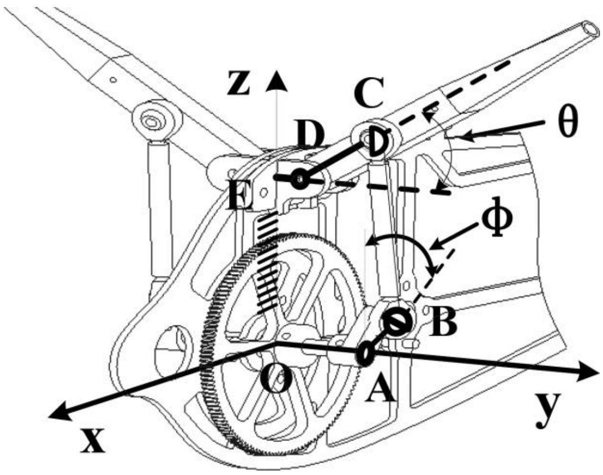


Figure 5.4: The Schematic Diagram of Flapping Mechanism

Table 1: Parameters of the FAV Prototype

Parameters	Values
Total mass	455 g
Stroke range	11°~45°
Flapping frequency	3~7 Hz
Kv value of brushless motor	Kv 3600
Battery	3S LiPo 11.1 V 800 mAh
Flight endurance	15 min

1. From the schematic diagram above we can see that OABCDE is then the spatial link mechanism which realizes the flapping motion. While AB is the crank which transmits rotational motion of motor, and CD is the rocker which acts as the wing radius. B and C are two spherical bearing pairs. Link BC transfer the rotational motion of crank AB to the reciprocating swing of the rocker CD. $\varphi$is the angle between crank AB and z axis, which refers to the angular position of the crank. And $\theta$is the angle between the rocker and y axis, which is used to denote the angular position of the wing.
2. When crank AB revolves at a constant speed, we specifically analyzed the angular position and angular velocity of the rocker CD. Figure5.6shows the two limit angles of the rocker during strokes and shows the variation of angular velocity the rocker CD when the flapping frequency is normalized to 1 Hz. We can see that the positive extreme angular position is 45°, and the lowest extreme angular position is –11°. During our fabrication of prototypes, we found that the length of the spatial link BC determines the stroke ranges of the rocker CD, and this range will greatly affect the pitching stability when flying.
3. According to the above simulation result, we can see that when crank AB rotates at a constant speed rocker CD swings circularly and accordingly, and at the mean time CD does not swing at a constant angular velocity. During down stroke, the angular velocity of the rocker first increases to a maximum value from a minimum velocity, and then decreases to a minimum speed. For up stroke, the changing process is to the opposite, increases first and then decreases. What calls for special attention is that the time elapse for the angular velocity increasing process of up stroke is the same as the time elapse spent in the decreasing process of down stroke, and the time elapse for the decreasing process of up stroke is the same as the time elapse spent in the increasing process of up stroke. The up stroke and down stroke process of the whole flapping period is completely antisymmetrical. Rocker CD reaches its highest angular velocity at the position of roughly the center of each stroke, which is about 17°.
4. The flapping motion in up stroke and down stroke are completely the same, which means theoretically speaking, the positive lift generated during the down stroke and the negative lift generated during the up stroke should be balanced out, however prototypes of this kind can still fly, which means the resulting lift forces are still positive. And this phenomenon shows that lift produced by flapping motion cannot be explained in a traditional way. Maybe theories like leading-edge vortex effect put forward by scientists can illustrate why our ornithopters can still make its fly

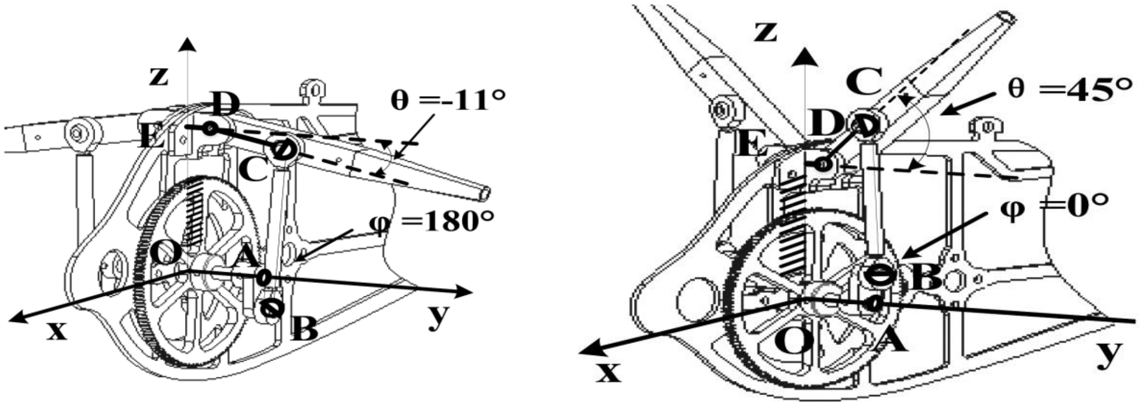


Figure 5.5: Angular Position of Two Extreme Position of Rocker CD

VII EXPERIMENTAL DETAILS

1) Indoor Experiments

After we have done the assembling work, we conducted both indoor and outdoor experiments to verify the performance of our prototypes. The indoor experiments conducted by hitching the prototype to the ceiling to flap at a certain frequency and usually flaps for at least five minutes, to make sure the structure will produce enough lift and thrust, and at the same time to guarantee the structure has good durability. The following pictures show the process of our indoor experiments. Figure6.1shows that we usually first fixed our prototype to a resilient mount which can beat up and down circularly when the FW-UAV flaps its wings, and Figure 6.1shows the scene when we hanging our FW-UAV to preliminarily check its aerodynamic performance.

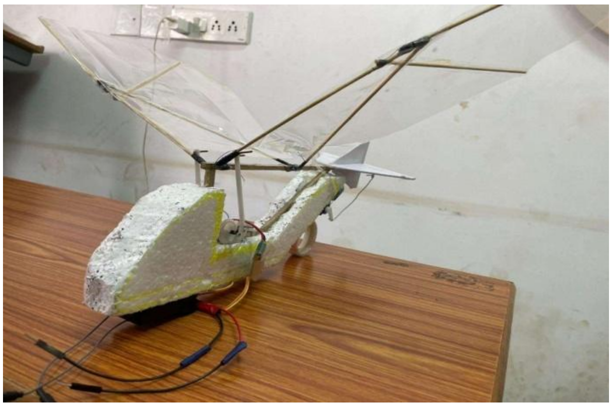


Figure 6.1: Indoor Experiments to Check the FAV's Mechanical Durability and Basic Aerodynamic Performance

2) Outdoor Experiments

After we have preliminarily examined our FW-UAV's mechanical and aerodynamic performances, we then conducted the outdoor experiments (see as Figure 6.2), i.e. free flight, to examine the systematical performance. Usually, the performance of free flight is affected by various aspects. Except from the mechanical and aerodynamic layout itself, the wind conditions and the operator's proficiency of remote controlling also play an important role. The following pictures show scenes when we were flying our FW-UAV prototype.

Figure 6.2: Outdoor Experiments

VIII COMPONENTS

Table 2:List of Components Utilized

Component Name	Materials & Use
1.Frame	Body Frame –Balsa Wood Main Frame
2.Wing Frame	Bamboo Sticks
3.Gear Assembly	Washing Machine Timing Gear Stage Gear Box a) Spur Gear b) Cluster Gear Gearing System
4.Mini Coreless Motor (Brushed Motor)	3.7Volt DC Magnetic Motor 58000RPM Stainless steel
5.Battery	Power Source a) 3.7V 200mahLi-Polymer b) 3.7V 300mahLi-Polymer
6.Thermocol	Frame Cover
7. PVC Foam Sheet	Gears holder
8.Thin PVC Sheet	Tail Section
9.Micro Servos	2 Model IDUINO SG90 Mass 99 Gm Operating speed - 0.2/60 Degree Stall Torque – 1 Kg/cm (4.8V) Operating Voltage – 2.8V – 4.2V
11.Transmitter	Flysky Channel-6 Model – Wing /Glider Power – 6V 1.5 AA*4
12.Receiver	FS-iA6B Power 4.0-6.5V RF Range 2,408-2.475GHz

IX CONCLUSION

We developed our FW-UAV prototype, and have done some preliminary analysis of both the transmission mechanism and flight data. Through experiments we have gained a lot of experience to make our FW-UAV better. However, we still haven't research deeply in how parameters like flapping frequency, stroke amplitude and the range of strokes affect dynamics of the flight. We need to model our prototype and based on that work out the corresponding control strategies to make sure it flies as expected. We will direct at these problems and give some more detailed and in-depth analysis in future works.

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