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Design, Fabrication and Analysis of Flapping Wing Micro Air Vehicle for Surveillance

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Abstract—**The focus of this work is to detail how the design process was undertaken to reach the completion of making a physical model of flapping wing micro air vehicle. It is also focused on the objective to select the appropriate flapping mechanism for the vehicle and also to select suitable power system. The power system consists of small electrical and mechanical components that all contribute to the flapping motion of the vehicle. Even though there is a lack of development in flapping vehicles compared to the fixed and rotary wing vehicles there is still a greater demand for flapping wing vehicles because, it can be used for surveillance without attracting enemies attention as it looks like a natural bird.**

Keywords—Flapping, bird, micro air vehicle, surveillance

I. INTRODUCTION

Flapping wing micro air vehicles are attracting many researchers now days. The flapping flight of birds, bats, and insects has fascinated many of researchers in various fields such as biology, zoology, aerodynamics, and electronics because their superior maneuverability and aerodynamic benefits especially in a low Reynolds number flight regime. That is used extensively to fly around in unknown environments. The light weight and small size of the robot significantly limits the energy, sensors, and onboard processing. In addition to this flapping wing propulsion is a fascinating research area where the extensive attention over the years is not withstanding and only the researchers with highly equipped laboratories and electronics were succeeded in achieving the stable flight. Because of this reason it is attempted to develop a flapping wing micro air vehicle with numerous efforts to mimic nature's sky ruling creatures using low cost techniques.

It is well known for the researchers that most of the early trials for "flying robots" which adopted the flapping mechanism for generating the thrust as well as lift; typical examples of the early design of flapping vehicles can be seen in the diagrams of da Vinci and Cayley. Now days the flapping vehicles were being forgotten because of the great success of fixed wing aviation. But the rebirth of flapping machines which can fly in the sky is occurring in the form of Unmanned Air Vehicles (UAV). This rebirth is mainly occurring because of the requirement of surveillance that should not attract the enemy's attention due to their shapes that looks like natural bird. The development of flapping wing MAV involves very complicated as well as very difficult technologies compared to that of the fixed wing aircraft and the propeller type of aircraft.

The birds as well as insects will have flexible wings which are anisotropic in nature and their wings will take some complicated motions which involve flapping, twisting and folding motions. So it is decided to make artificial flyers of very thin and flexible wing structures. The major advantage of flexible wing structures is to create motions of flapping and passive twisting. It also helps in developing aerodynamic forces and has major influence in flight stability and controllability. Flapping is restricted to do limited operations mainly involving take off, landing and stabilization. But during soaring the flapping wings act as fixed wing airfoils. Small birds use the flapping mechanism for generating loft to overcome their own weight thereby the flapping has become the most advantageous for flyers when compared to the mechanisms employed for fixed or rotating wings.

The problem faced in the previous works is the weight constraints of the control surfaces. The symmetry of the star board and port is not maintained so location of the center of gravity became the problem for stable flight. Due to heavy weight the power supply requirement increased drastically. The objective of this work is to develop a Flapping wing MAV. That is capable of vertical take-off, hover and land by using minimum amount of power supply. So that it can be used for Surveillance by using a camera in the vehicle.

II. METHODOLOGY

The clap and fling method is selected for designing the MAV. The clap and fling method is a method of flapping that generates more lift than the conventional flapping of bird wings. This method is mostly seen in nature by sparrows and some species of fly. The clap and fling method works by making the wings to meet rapidly at the leading edge of the wings so that the leading edge will first meet together then the flexible part of the wings will follow the same which is usually referred as feathering. The air is pushed out at the back when the wings come together and this will produce thrust which is altered to produce lift. When the wings come together they try separating each other that allows the air to rush in towards front and create suction which produces additional thrust. This effect will also create air circulation around the wings which will produce lift under kutta condition. Because of these reasons of control force production by naturally the power supply can be reduced and also it seems to be the best method to mimic the flyers. The method described above is illustrated as shown in Fig.1.

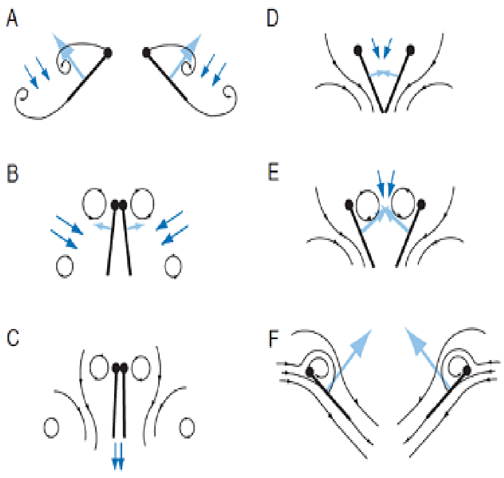

Fig. 1. Clap and fling method.

Fig.2. shows the overall working principle of the clap and fling method implemented model of flapping wing micro air vehicle. This model is operated by means of wireless communication by means of Radio Controlled Transmitter and Receiver. Flapping is done through micro brushless DC motor. The input signals are given through RF transmitter. The RF receiver receives those signals and run the brushless DC motor and the speed of the throttle is varied by means of sliding the knob in the transmitter and correspondingly the speed of the motor varies by means of Electronic speed controller that is inbuilt in the receiver.

There is also a provision for fixing a micro Wi-Fi camera with less weight for surveillance purposes. The camera sends the digital video signals through wireless fidelity which is received by the receiver and it is displayed in the monitor. This description shows the overall work that is carried out in the development of the flapping wing micro air vehicle.

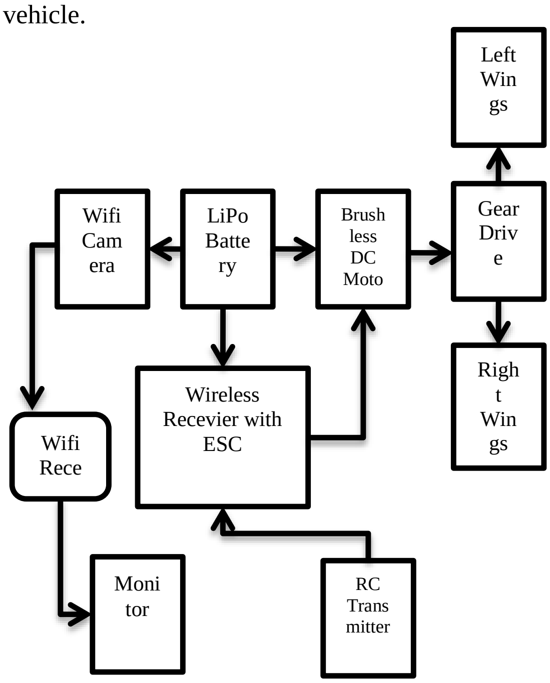

Fig. 2. Block diagram of Flapping wing MAV.

III. DESIGN AND FABRICATION

The modeling of flapping wing MAV which is capable of performing vertical takeoff, landing, hover in the air, and horizontal flight was done with the help of CATIA V5. Since it decided to use clap and fling method which requires four wings. So the vehicle consists of four wings and a tail surface which is used for increasing the stability and control. Even though the two wing concept is easy to design and fabricate but for efficient flying four wing concept is fixed.

The body which is the fuselage of the vehicle is made up of carbon rods of 1.5 mm thickness. Since the fuselage is the main load bearing part of the MAV carbon rods are used to increase the strength as well as less weight. The length of the fuselage is fixed as 300 mm so that it will match the wing span which is the design criteria for designing the aircraft.

Since it is decided to have four wings, these wings should not increase the weight of the MAV. So the wings leading edge is made up of carbon rods and the surface of the wings are made up of Mylar of 26 microns thickness. The shape of the wing is fixed with the rectangular shape with the tapered end so that the wing flutter is avoided. The span of the wings is fixed as 280 mm. This is chosen to mimic the sparrow's wing span. The tail of the wing is fixed as inverted V tail which follows the same design criteria as that of wings. To finalize the size of the wings, a lift equation governing the static wing governs for this flapping wing. The only difference is the propulsion. The airplane has a propeller which creates thrust whereas the flapping wing itself creates thrust. Although this wing shape is not rectangular There is a taper in the wing .This will ensure that the wing area is highest at the same time not increasing the wing flutter during flapping or moving forward in flight . Flutter may increase the structure's total vibration and drastically reduces the model's lift and thrust.

A. Lift Force Calculation

$$L = \frac{1}{2} \times C_L \times \rho \times A \times V^2 \quad (1)$$

Where L is the Lift force (N), V is the Air speed $(\frac{m}{s})$, A is the Area of the wing (m^2), C_L is the Coefficient of lift, ρ is the density of air $(\frac{Kg}{m^3})$. The density of air is taken as 1.225 $(\frac{Kg}{m^3})$. The area of the wing chosen is 0.0104 (m^2) and the air speed is taken as 10 $(\frac{m}{s})$. Coefficient of lift for low Reynolds number regime is 0.8.

By substituting the values the lift of the wing is given as 6.37 (N).

The four wings are connected to a hinge which is connected with the gear assembly so the rotating motion of the motor shaft is converted into flapping motion. The gears are assembled in such a way that it will spin parallel to the axis of forward movement. The speed of the chosen motor is about30000 rpm micro DC motor and the gears are used to increase the flapping frequency. Since from the literature survey it is required that the flapping frequency should be above 10 Hz.The gear ratio should be about 10-40 to achieve the desirable flapping frequency above 10 Hz. This ratio is achieved by using three gear wheel made of ABS. From a pinion of 9 tooth mounted directly on the motor shaft, the rotation is transferred over an intermediate wheel of 42/12 tooth to a third wheel of 84 tooth, resulting in a gear ratio of 32. The flapping actuation of the wing is achieved by a drive bar between the third gear wheel and the wing mounting, which means that the rotational frequency of the third gear wheel is equal to the flapping frequency.

B. Gear Ratio and Flapping Frequency Calculation

$$Gearratio = \left(\frac{42}{9}\right) \times \left(\frac{84}{12}\right) \quad (2)$$

Gear ratio =32 (3)

Thus 32 revolutions are required for 1 revolution of gear 3. That is 32 revolutions is required for 1 flapping motion but the speed of the motor is 30000 rpm i.e. 535.7 Hz.

Total flapping motion (frequency) $=\frac{rpm}{Gearratio}$ (4)

By substituting the known values, the total flapping motion (frequency) is found to be 15.62 Hz.

From the above calculation the flapping frequency for our model is 15.62 Hz which is more than sufficient to achieve the required lift of the model and also it is found that the flapping frequency is directly proportional to the speed of motor and indirectly proportional to the gear ratio.

Fig.3. Micro brushless DC motor and Battery.

C. Torque Calculation

The lithium polymer battery is chosen for its less weight and more durable. The motor chosen is Brushless Micro DC Motor. The speed of the motor is 30000 rpm, voltage supply is 3.7 V and current is 0.3A

The torque of the above motor is given by the formula

$$\tau = \frac{I \times V \times 60}{rpm \times 2 \times \pi} \quad (5)$$

Substituting the above values, torque of the motor obtained is **0.0003535 Nm.**

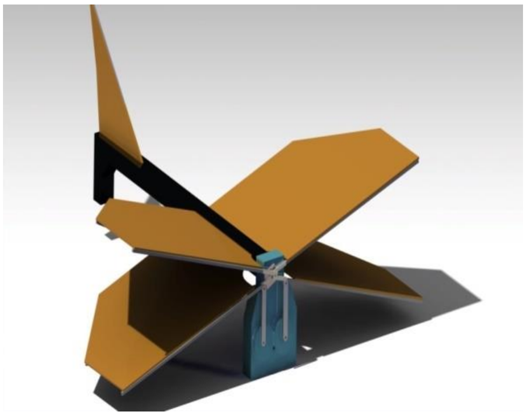

Fig. 4. Isometric View of the CATIA Model .

D. Electronic Speed Controller (Esc) and Receiver

For controlling the fabricated flapping wing micro air vehicle the radio control is used. The main objective is to control the speed of the micro DC motor there by controlling the flapping frequency of the vehicle. The radio controller consists of Electronic speed controller, Transmitter and Receiver. The control loop is formed between the micro DC motor, Electronic speed controller, receiver and transmitter which works together to provide stability and control. The control board which is installed in the vehicle consists of both receiver and the electronic speed controller in-build. The receiver consists of two channels and each channel consists of two pins. One pin is control pin which is connected with the motor for controlling the speed of the motor. Another pin is the supply pin which is connected with 3.7V LI-PO battery. The receiver consists of a switch which is used to trigger the frequency and match with the transmitter command signal. The receiver also consists of power jacket for charging the LI-PO battery. The receiver with in- build electronic speed controller is shown in Fig.5.

Fig. 5. Electronic Speed Controller (Esc) and Receiver.

E. Transmitter

RC Transmitter (2.4 GHz RC radio transmitter) is used to direct the flapping wing micro air vehicle in the air. A 2.4

GHz RC radio receiver which is installed in the vehicle receives commands from the RC transmitter on the ground which is a one way link. Receiver is the generally small match box size device to which the Transmitter sends its commands.

Fig. 6. Transmitter.

The transmitter consists of a sliding switch which is controlled from lower position to higher position to increase the speed of the motor from minimum value to maximum value. The transmitter is powered by four AA LI- ion batteries. The transmitter consists of an ON/OFF switch which is used to trigger the frequency and match with the receiver for sending command signals. The transmitter also consists of a USB slot for providing supply voltage for charging the battery which is installed in the vehicle.

IV. FINAL ASSEMBLY AND TESTING

A. Assembling

In the previous section the parts required for the operation of flapping wing micro air vehicle had been discussed. Now the parts such as body, wings and tail, hinge, drive train, motor, battery, electronic speed controller and receiver are assembled to form the final model of the flapping wing MAV which is shown in figure 2.1. First the drive train is connected with the body and it glued to remain stationary. This is because we are not going to vary the body and gear assembly dimensions. Then the wings made of Mylar and carbon rods are plugged in to the hinge holes. The tail section is connected to the rear end of the body which is used for the stability purpose. Finally the motor crank shaft is connected with the gears in the drive train to produce the required flapping motion by acquiring power from the battery. The receiver with in- build electronic speed controller is installed in the vehicle. The electronic parts are arranged in such way that the center of gravity of the vehicle lies at 30% of the chord of the wing.

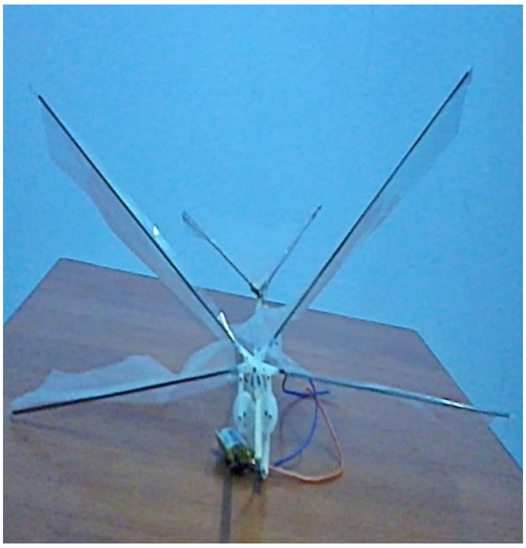

Fig. 7. Assembled Model of Flapping Wing MAV.

B. Final Testing

The final fabricated flapping wing model is tested to see whether the desired flapping motion is occurring in the vehicle. For testing, the model is tied with a rope and hanged from the wall. The rope is tied in the vehicle at the point of center of gravity of the vehicle so that the vehicle will remain stable as it is placed on the ground. Then the motor is connected with the control pin of the receiver and the battery is connected with the supply pin of the receiver. Then the transmitter and receiver are triggered to match the frequency spectrum. Then the throttle knob of the transmitter is slowly raised, while raising the vehicle starts moving forward and undergone a motion with circular path. This shows that the vehicle is producing the motion instead of remaining stationary. The final testing of vehicle with the rope is shown in Fig.8.

Fig. 8. Final Testing Of Flapping Wing MAV.

C. Flying Time Caculation

Li-Po Battery specifications are essential for calculating appropriate flight time of micro air vehicle. The Electric charge capacity of chosen battery is 70mAh and discharge rate is found to be 10C to 20C. Maximum Flying Time is found from the formula

For maximum the Constant current draw is:

$$= \frac{\text{Electric charge capacity} \times \text{Discharge rate}}{1000} \quad (6)$$

By Substituting the known values, the constant current draw is found to be 0.7 A

$$\text{Flying time} = \frac{\frac{\text{Electric charge capacity}}{1000}}{\text{Constant current draw}} \quad (7)$$

Calculating with the above values, flying time is 0.1 hours that is equal to 6 minutes.
Minimum Flying Time can also be found by the following equation.
For minimum the Constant current draw is:

$$= \frac{\text{Electric charge capacity} \times \text{Discharge rate}}{1000} \quad (8)$$

By Substituting the known values, the constant current draw is found to be 1.4 A

$$\text{Flying time} = \frac{\frac{\text{Electric charge capacity}}{1000}}{\text{Constant current draw}} \quad (9)$$

Calculating with the above values, flying time is found to be 0.05 hours that is equal to 3 minutes.

From the above calculations the flying time of the vehicle is calculated theoretically by using the discharge rate and electric charge capacity of the battery as the main parameters. It is found that the flying time is minimum i.e. 3 minute at maximum discharge rate of 20c and the flying time is maximum i.e. 6 minute at the minimum discharge rate of 10c. The variation in the flying time is due to variation in discharge rate which is caused by way of flying and external factors such as resistance, weight and wind.

D. Weight Forecast

The weight of the flapping wing micro air vehicle is found after the entire electronic components are assembled in the vehicle. Because of the weight factor it is concentrated on selecting the less weight motor, battery and controller even though they are little bit costlier than the conventional one. In order to do some of the calculations outlined before, an estimate of the total mass of the vehicle was necessary. Table 1 shows a breakdown by components of the respective weights. From the table it is calculated that the total weight of the flapping wing micro air vehicle is nearly 64 grams. The values presented were rounded to the nearest gram.

TABLE 1: WEIGHT FORECAST

ITEMS	UNIT MASS (g)
Motor	15
Battery	10
Receiver	5
Antenna	3
Fuselage	15
Tail	3
Wings	7
Extra connectors and cables	6
Total	64

V. CONCLUSION

Thus the flapping wing MAV model is designed and finally fabricated. The final fabricated model is tested with rope for its stability and functionality. The control force of the vehicle is found practically by using strain gauge setup which measures strains induced in the vehicle. The work can be extended by testing the performance of flight by using various configurations of the wing contour profile and the analysis of the vehicle with all configurations can be performed.

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