Development of Tailless Flapping Wing System With 2.4 GHz Wireless Communication

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ABSTRAK

Sekarang ini, telah banyak studi tentang karakteristik terbang burung kecil dan serangga di mana di dalam kategori ukuran ini, desain flapping wing (kepakan sayap) unggul atas desain fixed-wing. Meskipun demikian, kompleksitas gerakan dan biomekanisme sayap burung dan serangga memperbanyak kesulitan dalam pembuatan sistem kepakan yang efisien, terutama yang tidak memiliki konfigurasi ekor. Dalam upaya untuk mengatasi kesulitan tersebut, dikembangkan dua sistem kepakan sayap (FW-MAV) tanpa konfigurasi ekor. FW-MAV yang pertama hanya memiliki satu motor untuk menggerakkan sayap dan dapat ditambahkan sebuah magnetic actuator untuk menambah kemampuan manuvernya. Sedangkan yang kedua memiliki dua motor yang secara terpisah dapat mengepakkan dua sayap. Sarana komunikasi nirkabel 2,4 GHz juga ditambahkan untuk mengontrol jarak jauh kedua sistem FW-MAV. Kemudian, tingkat efisiensi terbang kedua FW-MAV diukur berdasarkan simulasi kinematika dan frekuensi kepakan. Selanjutnya, gaya dorong yang dihasilkan oleh kedua FW-MAV juga diukur dan dibandingkan. Berdasarkan pengukuran tersebut, FW-MAV dengan dua motor memiliki berat 4% lebih besar dari model dengan satu motor, tetapi dapat menghasilkan sudut kepakan 10% lebih besar dan 3 kali lipat gaya dorong.

Kata Kunci: *Flapping wing MAV, komunikasi nirkabel 2.4 GHz, four bar linkage, mekanisme roda gigi, pengukuran gaya dorong.*

ABSTRACT

Recently, there have been studies on characteristics of flapping motion of small birds and insects in flight where in that size category; flapping wing designs excel over their fixed wing counterparts. Despite that, complexities of wing motion and biomechanism of birds and insects added many difficulties to build an efficient flapping mechanism, especially that without tail configuration. In an attempt to overcome such difficulties, two motor-driven flapping wing system micro aerial vehicles (FW-MAV) were developed without tail configuration. First FW-MAV has one DC motor to drive its wing motion and optionally magnetic actuator for maneuverability. The second FW-MAV has two DC motors that can separately generate flapping wing motion. In addition, 2.4 GHz wireless communication was also implemented to both FW-MAV to remotely control the wing actuators. Then to evaluate their flight efficiency, flapping motion of the two FW-MAVs were evaluated based on kinematics simulation and flapping frequency test measurement. Further, thrusts produced by both FW-MAVs were also measured and compared. Based on the measurement, FW-MAV with two motors was about 4% heavier than the other FW-MAV, but it can generate about 10% larger flapping angle and about 3 times of thrust.

Keywords: *Flapping wing MAV, 2.4 GHz wireless communication, four bar linkage, gear mechanism, thrust measurement.*

1. INTRODUCTION

Nature flyers such as small birds or insects, even though they are flying in much the same way by flapping their wings, they have totally different forms of flapping wings motion [1]- [4]. Birds wing motion consists of flapping, lead-lagging, feathering, flexing, spanning and twisting [5]-[11]. In contrast, insect wing motion can be explained as various principles, such as a role of wing rotation [12], leading edge vortex [13], and clap-fling [14]. Because they do not have a tail, most of the insects can only use their wing as a control surface for maneuvering and keep their flight stability. In observation of aerodynamic principles of flapping flight [15], insects show that they are flying with an unsteady aerodynamic mechanism in such low Reynold number that gives more complexity at the study of the forces generation in insect flight [12]-[18]. In addition, many biological observations have found that insects have a corrugated wing by a combination of three-dimensional vein structure and membrane [19] -[20]. With their wing configuration: low wing aspect ratio and zig-zag cross section, insects can generate a very efficient aerodynamic force in a low Reynolds number. Their flexible wing is also very strong to handle the acting forces on its surface and create a large flapping angle. These characteristics of insect flapping wing have been difficulties to build an efficient flapping mechanism as well as fabricating bio-mimetic wings due to the limited materials and actuator realization.

Instead of those difficulties and limitations, many researchers have been successfully built a FW-MAV that can fly remotely at some reasonable flight time endurance (Figure 1). Most of these successful flights use a DC motor as the actuator of its mechanical system and a LiPo battery as the power source of the FW-MAV [21]. Wing structure and body frame configuration are made of a non-metal lightweight material such as carbon pipe / sheet / rod, balsa wood, or thin polystyrene [21]. And the wing membrane is usually made of thin films with lightweight supporting rods [23]-[24].

Figure 1. DelFly II [21]

Encouraged by these significant progress in recent biomimetics works and recent successful flights of a flapping wing system [21]-[24], two prototypes of a palm sized FW-MAV with no tail configuration (Figure 2) have been developed in this work. The first FW-MAV, Prototype 1, utilized one electric DC motor to generate flapping motion of two wings. Optionally a magnetic actuator can also be inserted to this flapping configuration to generate active wing twist and add maneuverability. In the other hand, the second FW-MAV, Prototype 2, utilized two electric DC motor to control the flapping motion of each wing. The two prototypes have same size: 115 mm of wing span and body length of 67 mm.

Both prototypes of the FW-MAV can be controlled remotely with wireless communication of 2.4 GHz. To control all electrical devices and wireless communication, a microcontroller of 8051-core was assigned to the FW-MAV. An electrical circuit was used and connected to a dipole antenna system to initiate data communication with the remote controller (Figure 3). With this remote controller, the FW-MAV can provide up to 5 channel of command for flight control including control for two wing system.

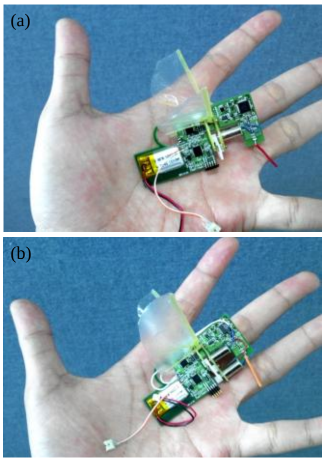

Figure 2. Palm sized FW-MAV. (a) Prototype 1, single motor-driven FW-MAV (b) Prototype 2, two motor-driven FW-MAV.

Figure 3. Remote controller.

Performance measurements of two prototypes were conducted with consideration of simple and easy-to-use experiment system. Flapping wing angle and mechanical motion of the FW-MAV were observed and calculated based on kinematics simulation and measurement system using combination of laser receiver and transmitter. Thrust of two FW-MAVs were also measured by using single-axis load cell. Then finally, performances of two FW-MAVs were compared to evaluate force generation and weight increment from actuator system.

2. DESIGN AND FABRICATION

Design of the FW-MAV (Figure 4) was derived from a simple four bar linkages with gear mechanical system. The linkages were implemented to the FW-MAV to transfer rotary motion from the motor to the flapping wing system without tail configuration. Therefore, all the FW-MAVs flight motions, such as roll or yaw, were controlled by wing motion.

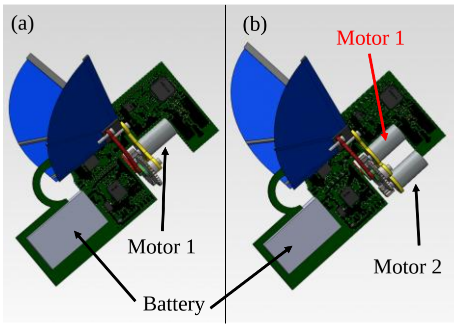

Figure 4. CAD Design of FW-MAV. (a) Prototype 1. (b) Prototype 2.

In this design, rotary motion of the motor was transferred to gear mechanical system and converted to up and down motion. The gearing system utilized three gears: two spur gears and one pinion gear, as shown in Figure 5. The two spur gears are connected and rotated by pinion gear that is connected to one of them. The pinion gear has diameter of 3.6 mm and ratio of 1:3 with spur gear.

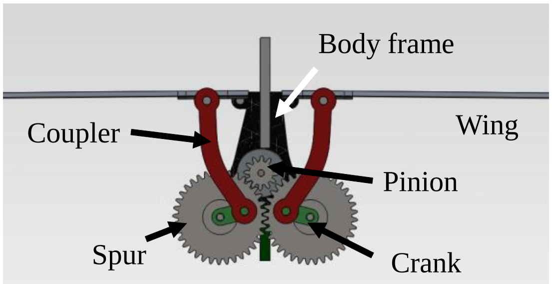

Figure 5. Mechanical design of the FW-MAV

To simplify the mechanical design of the FW-MAV, a four-bar linkage system was used and optimized with gear mechanical system. Configuration of crank and coupler of the four-bar linkage can generate 90^{o} of total flapping angle. The crank was fixed on the spur and rotated with the same direction and angular velocity as the spur gear. The crank has a pin that engages the hinge of the coupler so that the rotary motion of the crank is directly transferred to the motion of the wing.

Table 1. Dimensions of the FW-MAV

Parameter	Prototype 1	Prototype 2
Span (mm)	115	
Height (mm)	30	
Weight (g)	9.0	9.4
Length (mm)	67	
Wing Area (mm^2)	1108	
Links (mm)	3	3.3
Coupler (mm)	14	

Based on Table 1, output flapping angle of 90 degree was generated by the corresponding lengths of links, e.g. 3 mm of crank for prototype 1 and 3.3 mm for prototype 2, 14 mm of coupler and a 4 mm of distance between coupler hinge on the wing with center of the wing rotation. It can also be seen that the prototype 2 was about 4% heavier than prototype 1 because of the difference in actuator system configuration.

3. PERFORMANCES

Performances of the FW-MAV were measured based on flapping angle, flapping cycle, and thrust generation during flapping motion of two prototypes. The flapping angle was calculated based on CAD simulation and four bar linkage analysis. Flapping motion of FW-MAV was also observed using a simple combination of laser transmitter and receiver to measure the flapping cycle time. Performance of the two prototypes was also evaluated based on thrust of both FW-MAVs which were measured using load-cell. To test the accuracy of the measurement system, especially that by load cell, a PWM with only about 30% duty cycle (a half of maximum speed) was used to power up the actuator system (DC motor) of the FW-MAV. By this limitation, the performances of both prototypes were compared each other to evaluate the efficiency of the tailless FW-MAV.

3.1 Flapping Angle Measurement

On the FW-MAV, the flapping motion can be seen as a rate of change in flapping angle. Therefore, to investigate the flapping motion of the FW-MAV, a kinematics simulation was conducted by using CAD software (SolidWorks). In the CAD software, the FW-MAV was fully built with details of mechanical system and electrical devices. The CAD software then calculated the motion of all parts of the model and generates an output of FW-MAV's flapping angle.

As shown in Figure 6, four bar linkage analysis can be also derived from linkage configuration of two prototypes to calculate flapping angle trajectory. Based on Table 1 and CAD model, the linkage configurations of two prototypes are: 4 mm of R4, 14 mm of R3, 14.2 mm of R1, and 3 mm of R2 for prototype 1 and 3.3 mm of R2 for prototype 2.

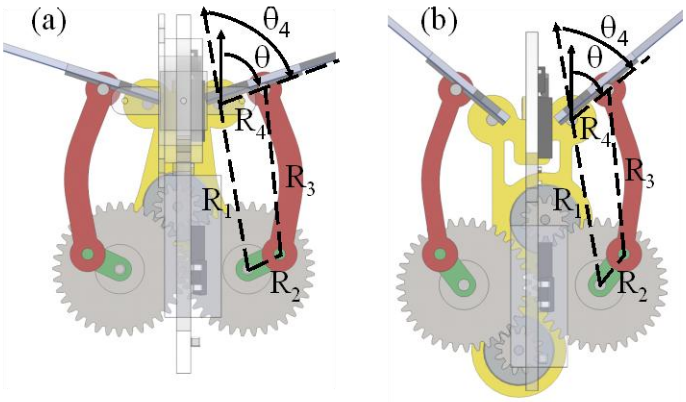

Figure 6. Linkages System of two FW-MAV. (a) Prototype 1 (b) Prototype 2.

Based on four bar linkage analysis [25], it can be concluded that

$$\theta_4 = 2\tan^{-1}\left(\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}\right) \quad (1)$$

where:

$$A = \cos(\theta_2) - k_1 - k_2\cos(\theta_2) + k_3$$
$$B = -2\sin\theta_2$$
$$C = k_1 - (k_2 + 1)\cos(\theta_2) + k_3$$
$$k_1 = \frac{R_1}{R_2}$$
$$k_2 = \frac{R_1}{R_4}$$
$$k_3 = \frac{R_2^2 + R_4^2 + R_1^2 - R_3^2}{2R_2R_4}$$

By varying θ_2 , the flapping angle trajectory θ_4 can be calculated during flapping cycle as shown in Figure 7. The flapping angle trajectory based on CAD simulation is similar with that on four bar linkage analysis. From Figure 7, it can be concluded that prototype 2 can generate about 100° of total flapping angle which is about 10° larger than that of prototype 1. The difference in total flapping angle between prototype 1 and 2 is because of the length of R_2 (about 0.3 mm difference).

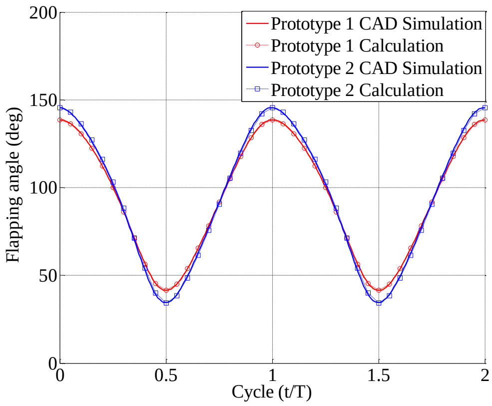

Figure 7. Flapping angle trajectory

3.2 Flapping Frequency

Flapping frequency of two prototype was measured by using a combination of laser transmitter and receiver. The laser receiver was connected to an oscilloscope to track the laser detection during flapping motion. As shown in Figure 8, a laser transmitter generated a laser source and created a straight laser line through air to the phototransistor. When the flapping wing flaps through the line during a flapping cycle, it will generate a peak in oscilloscope indicator as shown in Figure 9.

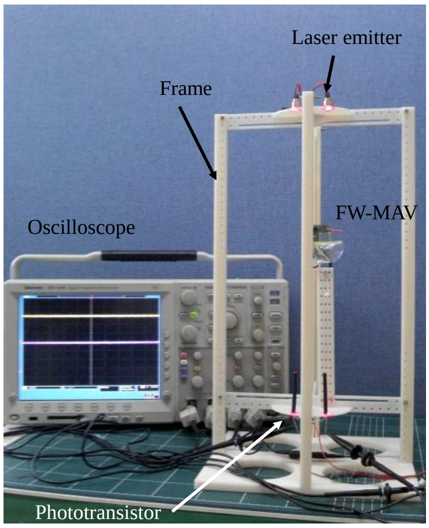

Figure 8. A simple flapping frequency measurement system

Two laser transmitter and receiver were aligned carefully to detect the flapping motion during upstroke and downstroke. Therefore, two channel of oscilloscope were also used to detect the peak of flapping motion from upstroke to downstroke, as shown in Figure 9.

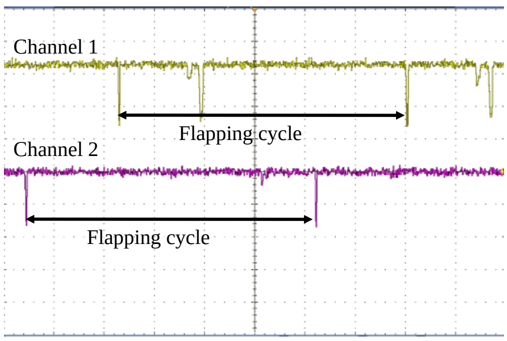

Figure 9. Oscilloscope indicator

From Table 2, it can be concluded that prototype 2 has higher flapping frequency than prototype 1, even the prototype 2 has larger flapping angle. This result shows that prototype 2 can generated about 30% faster flapping motion than prototype 1, with flapping angle about 14% larger.

Table 2. Measured Flapping Frequency

FW-MAV	Proto 1	Proto 2	Difference
Flapping Frequency (Hz)	8.7	11.4	31%

3.3 Thrust Measurement

To measure the thrust of two prototypes, a single axis load cell (Kyowa, 20mN) was attached to the frame and connected to prototype frame by a carbon tube (Figure 10). During flapping motion, the prototype generated thrust that pulled the carbon tube and was measured by the load cell.

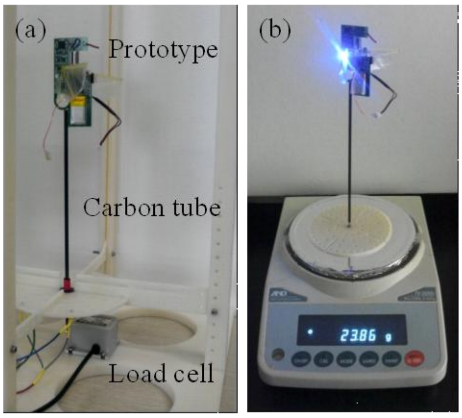

Figure 10. Thrust measurement system

The thrust of two prototypes was also measured by using a weight balance (0.001 gram precision) to validate the thrust measured by load-cell. As shown in , thrust measured by load cell has similar results with that by weight balance with difference about 3%. The thrust generated by prototype 2 is about 3 times than that generated by prototype 1.

Table 3. Thrust Measurement Comparison

FW-MAV	Weight Balance	Load Cell	Difference
Prototype 1	0.089	0.0843	2.9%
Prototype 2	0.304	0.2958	2.7%
Difference	-	278%	0.40

4. CONCLUSION

Two tailless FW-MAV have been tested in this work. The first FW-MAV has a single motor to generate the flapping motion and the second FW-MAV utilized two DC motor to generate flapping motion. Second FW-MAV was about 4% heavier than the first FW-MAV, but it can generate about 10% larger flapping angle and about 3 times of thrust. Therefore, it can be concluded that the second FW-MAV prototype has a better performance than the first one.

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