Mechanism Designs for Bio-inspired Flapping Wing Robots

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Abstract

This paper presents the design of flapping systems for small air vehicle used in surveying robot for an area that is hard to access. This paper also focuses on flapping mechanism of micro unmanned aerial robots that are similar to birds and insects. Our design consideration will have a wingspan up to 15 centimeters. Enable technologies for fabrication of these designs are 3D printers by using polymer materials with low density and weight. Characterizations of flapping wings are simulated and examined in this paper. This micro flapping wing robot will be tested and performed in real environments.

Keywords: Micro Robots, Flying Robots, 3D Printers, Surveying Robot

1. Introduction

Flapping wing robots are inspired from nature and developed for several mechanisms. Main objective is to improve flying characteristics by imitating the flight of birds and insects [1-2]. Recent challenges are volume of devices, accessibilities, strength of material, and stability control of the flight. Designs of flapping wing robots are studied for many perspectives, for example, geometry and materials of wings, flapping mechanism, mechanical structure, radio system control, CFD (Computational fluid dynamics) analysis and power sources. Flapping mechanisms are investigated by using several methods. By using a commercial 3D printer, C. Richter and H. Lipson [3] fabricated a four-wing robot with a total weight of 3.89 grams. For analysis of aerodynamics of flapping wing robots, H. Liu *et. al.* [4] has built a flapping wing robot and studied flow of air when the flapping robot is moving. This robot contains a clap and fling mechanism. Moreover, D. Mueller and J. W. Gerdes [5] designed a flapping wing robot by using a crack rocker mechanism. This study examined several folding mechanism for measuring a lift force in each design. J. H. Han *et. al.* [6] has reviewed information about flapping wing robots for a wing structure, flapping wing mechanism, flight control, and power source. H. Y. Chao *et. al.* [7] has compared specifications on microcontroller boards. For a power supply of flapping wing robots, M. Karpelson *et. al.* [8] has collected information about advantages and disadvantages in each type of power source. This study focuses on the mechanism design for bio-inspired flapping wing robots with a 3D-printer construction.

Different mechanism designs are evaluated and tested for the lift force measurements.

2. Design

2.1. *First Generation Design*

Our first design of flapping wing system is a Scotch yoke mechanism. The structure of this robot is made of ABS (Acrylonitrile Butadiene Styrene) plastics. In this study, the Scotch yoke mechanism is chosen for movement because this mechanism can move continuously and generate a high transmission force. This design consists of linkages to a DC motor and a circular disc. Figure 1 shows a concept design of the first generation. When the circular disc is rotating, the T-shape linkage and the wing will consequently move upward and downward.

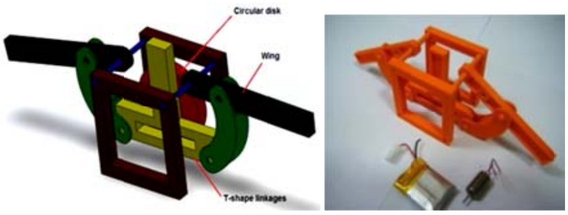

Fig. 1. The first generation of mechanism design for the flapping-wing robot. (a) CAD model (b) Fabricated prototype.

A testing result for the first generation showed that the T-shape linkage can move upward and downward in a slot wall. However, the gap distance between the slots of the upper part is larger than the width of the T-shape structure. This issue causes the inefficiency of the manipulation and the two wings cannot move simultaneously. Moreover, the T-shape linkage also moves with a high friction from the slot wall. It is also observed that the speed of flapping is reduced when the width of the slot is smaller.

2.2. *Second Generation Design*

As a testing result from the first generation, the second generation design is modified by using a crank rocker mechanism to reduce a friction in the assembly. In addition, the size and weight of the second design are reduced. Figure 2 shows a concept design of the second generation. The total weight of this design is eight grams. For these modifications, the point of rotation consists of two pivots and four joints to reduce the forces that act at wing.

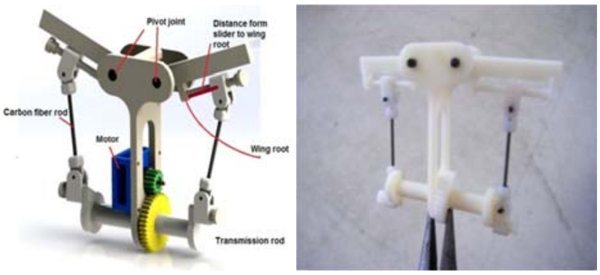

Fig. 2. The second generation of mechanism design for the flapping-wing robot. (a) CAD model (b) Fabricated prototype

When a DC motor rotates, the pinion gear drives the driver gear which is connected to a transmission rod. Two sides of transmission rod are linked to the carbon fiber rods that are connected to flapping wings. Carbon fiber is chosen for assembling this structure because it has a low weight and a high durability for external force. When the transmission rod rotates, carbon fiber rods push and pull a connected wing for upward and downward motions.

2.3. *Third Generation Design*

As a result from the testing, the second generation design still has a heavy weight. This design is improved for the size and weight. Material for this mechanism has also been changed from ABS plastics to a carbon fiber rod. The total weight of this design is reduced to six grams as shown in Figure 3.

Fig. 3. The third generation of mechanism design for the flapping-wing robot.

3. Theoretical and Testing Analysis

Mechanical structures of the flapping-wing robots are analyzed for flight characteristics. Main parameter for this study is to analyze a wingspan angle. These wingspan angles are influenced by the length of carbon fiber rods and the distance from pivot points to the carbon fiber joints. This location is on a sliding bar that is connected to the wing. Mainly, the second generation design is characterized for a wingspan angle that is an angle of wing between upstroke and downstroke flight. The mathematical calculations are formulated by using Crank-rocker theorem in Gashof law and cosine rule.

This experimental results of wingspan angle correspond to the theoretical analysis. In figure 4, the different length of carbon fiber rods does not significantly affect to the values of wingspan angles. The range of averaged values of wingspan angles is between 35 and 40 degrees. In figure 5, the distance from slider to wing root affects to wingspan angles. It is observed that increasing distance from slider to wing root will result to a decreasing wingspan angles.

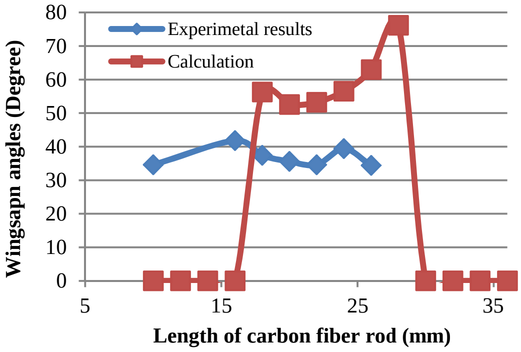

Fig. 4. Comparison between calculation and experimental results for different lengths of carbon fiber rod (when the distance from slider to wing root is 12 millimeters).

4. Wing Design and Testing Flight

For a flight take-off, micro gear motor (gear ratio of 14:9) is used for an electrical actuator. The length of carbon fiber rod is 20 millimeters and the distance from slider to wing root is 10 millimeters. Flapping wing robots are assembled to wings that are made of plastic sheet. The length of wing is 15 centimeters. The structure of the wing is a plus-like shape. Two conditions of wing structure are evaluated for a testing flight. The first design is the wing structure with only carbon fiber. The second wing structure has rubber rods for a bending area when a robot is flapping. The objective of rubber rods is to enhance a wingspan angle. Figure 5 shows these two concept designs of the wing structure. It is assumed that the wing can collect more air under the wing with the rubber rods. This air collection under the wing becomes a thrust force for a flapping wing robot. Figure 6 shows the prototype is set up wing.

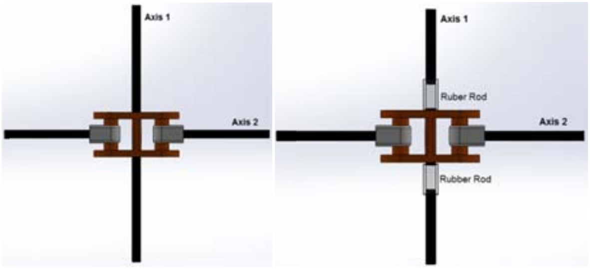

Fig. 5. Layout of two different wing structure (a) with only carbon fibers. (b) with rubber rods for a flexible wing.

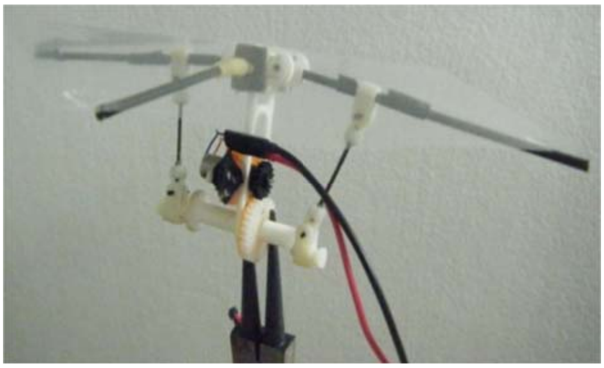

Fig. 6. Third prototype is setup with the second design of wing structure. Wing is made from plastic sheet with a wingspan of 15 centimeters.

In testing flight, the measurement of lift force is evaluated for these bio-inspired flapping wing robots. The values of lift forces are approximated for the change in weight on a precise scale. The robots are hanged on a suspension and a rope is used to connect these robots to the scale as shown in Figure 7. When a robot is flapping, a tension force from the rope changes the weight value on the scale. This change in weight represents an approximated lift force of the flapping wing robot.

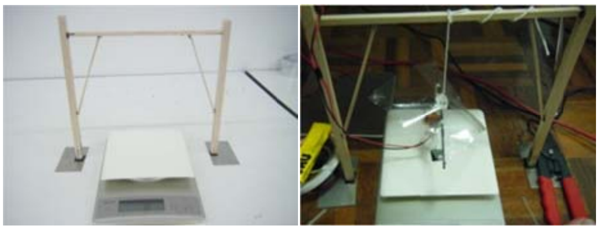

Fig. 7. A test setup with a suspension beam and a precise scale for measuring a lift force for bio-inspired flapping wing robots.

As a testing result, the first wing structure can generate an averaged lift force at 1.5 grams. The second wing structure that contains rubber rods can generate an averaged lift force at 2.5 grams. The performances are compared in Table 1.

Table 1 Comparison on performances of bio-inspired flapping wing robots for difference wing structures at 5 V.

Wing Structures	Wing span (cm)	Flapping angle at axis 1	Total weight (g)	Avg. lift force (g)
Using only carbon fiber	15	0	6.6	1.5
Adding rubber rods for a flexible joints	15	15	6.7	2.5

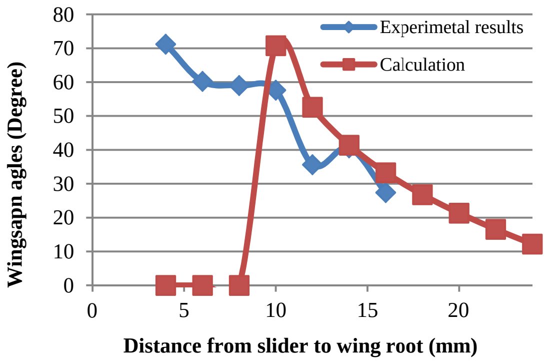

Fig. 5. Comparison between calculation and experimental results for different distance from slider to wing root (when the length of carbon fiber rod is 20 millimeters).

5. Conclusion

This study shows the design of bio-inspired flapping wing robots by using a 3D printer. The final design has a total weight of 6.6 grams. Moreover, the two different wing structures are analyzed for a lift. It is observed that the flexible joint with rubber rods can generate a higher lift force than the rigid wing structure. Hence, a flexible joint can increase a lift force for a bio-inspired flapping wing robot. However, these structures cannot generate an efficient lift force to overcome a weight of the robot. The modifications of motor speed and wingspan length will be implemented to improve the performance of these robots.

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