DESIGN OF A NOVEL FOLDABLE FLAPPING WING MICRO AIR VEHICLE

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ABSTRACT

This paper presents a novel foldable flapping wing micro air vehicle (MAV). This design of the proposed MAV is inspired from origami bird with flapping wings. The proposed method has two major advantages: 1) it eliminates the need for the utilization of heavy materials during manufacturing; 2) the bio-inspired flapping-wing mechanism replaces ornithopter mechanism, both of which are commonly encountered in MAVs. In the framework of this study, mechanical design of the foldable bio-inspired MAV, preliminary finite element simulations, and manufacturing process of the foldable MAVs are reported.

INTRODUCTION

In recent years, micro air vehicles (smaller than 15 cm [Petricca et al., 2011]) have been popular in military and civilian application such as aerial surveillance and delivery.

The bio-inspired flapping-wing design is a growing area and engineers have been searching a way to how to adapt flapping motion concept into their design. Generally, people in this area have been using the ornithopter mechanism to emulate low Reynolds number flyers [Wang et al., 2010]. However, ornithopter mechanism needs to gear transmission system and long linkages besides actuator and does not present a biocompatible solution and it takes time to assemble parts. In recent years, researchers in bio-robotic field designed monocoque bodies for MAVs using polymer based and lightweight materials in order to reduce the number of assembled parts [Lau et al., 2014]. In their study, carbon-fiber reinforced polymer is used to produce the body of the MAV which is not a feasible solution for manufacturing. In this regard, this paper focuses on an origami-based design which can be easily manufactured and which results in a very lightweight MAV. Recently, origami-based designs have been preferable in the aeronautics field. Researchers proposed a novel water landing system for multi-rotor aerial robots using deployable origami structures [Le et al., 2015]. These structures can be mounted at the bottom side of each propeller and can be expanded during emergency situations. In this work, the paper sheets are used to fabricate low-cost, light and a monocoque chassis. One mini servo linear actuator is preferred to

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perform flapping motion of wings and 3D-printed linkages are used to give airfoil shape of the wings and polydimethylsiloxane (PDMS) material is used to cover the airfoil. Lastly, Finite Element Analyses (FEA) are presented.

The goal of this study is to design a new, cheap and light flapping wing technique for MAVs by eliminating transmission members. The basic design of mechanical members, chosen materials and FEA simulations are shown.

METHOD

Mechanical Design

In order to decrease the weight and cost of the MAV, an origami-based foldable design is sought. Foldable structures have received great attention in the aerospace industry because of their ease of packaging and fabrication [Felton et al., 2014]. Several years ago, researchers from National Aeronautics and Space Administration (NASA) and Brigham Young University (BYU) developed an origami-based deployable solar panel [Zirbel et al., 2015]. The panel is folded and stowed in launch vehicle and after its deployment, the diameter of the structure can be expanded up to ten times larger than its initial diameter which is a good example of the impact of design by origami that provided a compact solution for payload structures. In this work, as a starting point, a sheet of paper (15 cm x 15 cm) is used in order to understand the basic mechanism of origami flapping bird. However, in the future, a cellulose acetate sheet (Fig. 1 d) will be utilized instead of paper sheet due to its durability and stiffness.

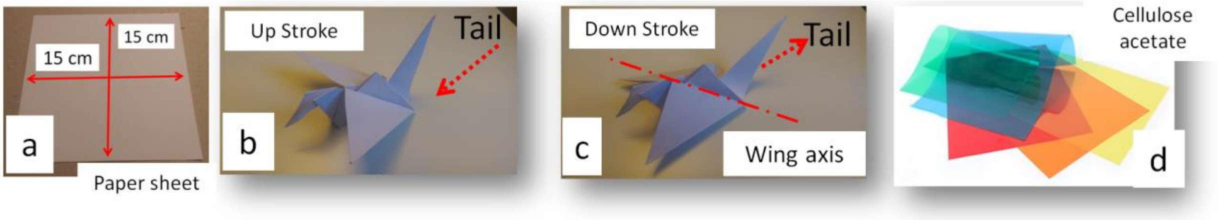

Figure 1: a) 15cm x 15cm paper sheet b) Upstroke generation c) Downstroke generation d) Cellulose acetate (Coloured 8.5x11 in. Acetates)

Figure 2: Origami bird made by cellulose acetate

The origami bird made by cellulose acetate paper is given in Figure 2. During the production of the proposed body of MAV, folding lines play a major role to obtain precise folded geometry. In order to obtain smooth folding lines, laser cutter machine is used. The cellulose acetate paper sheet is fixed to the platform of laser cutter machine and folding lines are obtained as dotted lines.

Figure 1 shows the proposed folded flapping-wing bird structure and upstroke and downstroke motions of its wings. The upstroke and downstroke generated by push and pull of the tail resulting a flapping wing motion. In Fig. 3 a and Fig. 3 b, major surfaces of the origami bird are tagged and it can be seen that the green and yellow regions in Fig. 3 are directly connected to the inner and outer side of the wings. They play an important role to create a bending moment around the wings axis. In this study, green and yellow regions shown in Fig. 3 will be called as the hinge joint. In order to analyze the folded bird structure; it is unfolded and the dimensions of each edge are obtained. The significant part for the CAD model of the hinge are shown in Fig. 3 c, e

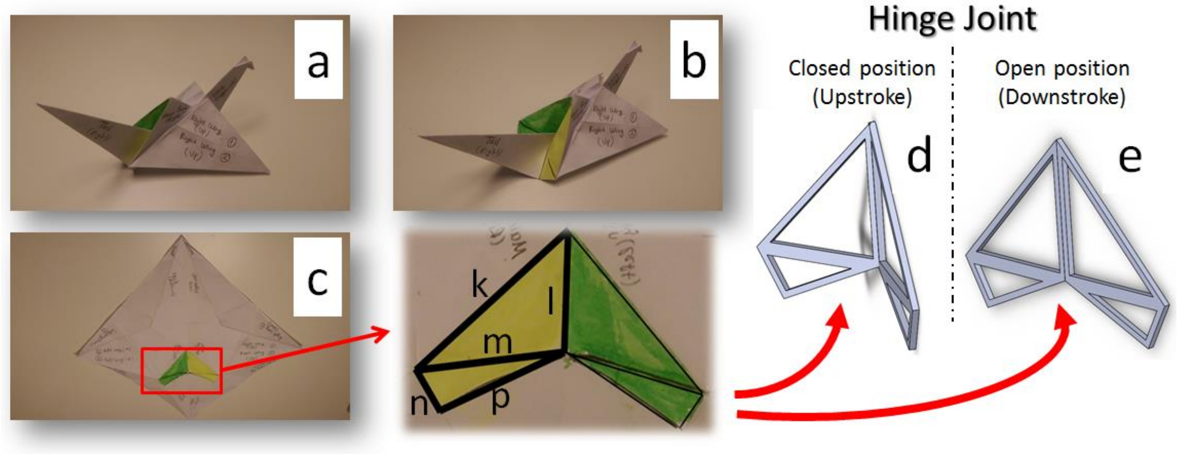

Figure 3 : Folded bird structure and hinge joint shape a) Upstroke b) Downstroke c) Unfolded origami bird d) Hinge position for upstroke e) Hinge position for downstroke

After understanding how flapping mechanism works, full CAD model is drawn as shown in Figure 4

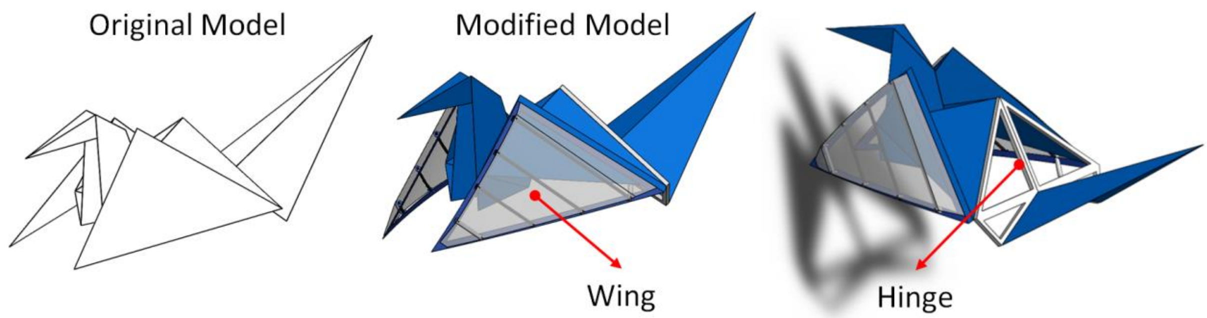

Figure 4: Original and Modified CAD model of the MAV

Figure 4 shows the comparison of the original and modified models for the designed MAV. As it can be seen from Figure 4, a specific area is subtracted from the wing frame and wing frame is covered with a thin film by using 3D-printed bars. In addition, hinge joint is attached to the main body of MAV and modified model is presented.

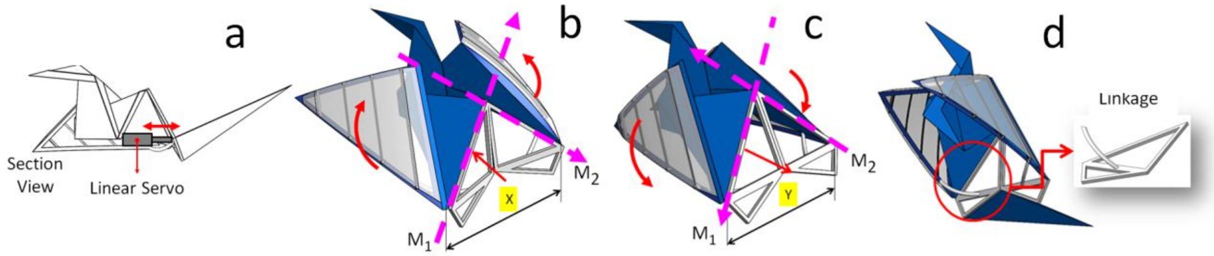

Figure 5: Flapping mechanism a) Linear servo b) M_1 and M_2 for upstroke c) M_1 and M_2 for downstroke d) Linkage between wing and hinge joint (inner connection)

In order to perform flapping motion of the wings, a linear servo actuated system is used as shown in Figure 5. The hinge joint directly connected to the wings from inner and outer side of the wings. As the servo motor actuate the hinge's forward and backward x and y lengths change due to the material's elasticity and create M_1 and M_2 moments (Figure 5 c). In addition, hinge joints are connected to the wings with linkages as shown in Figure 5 d.

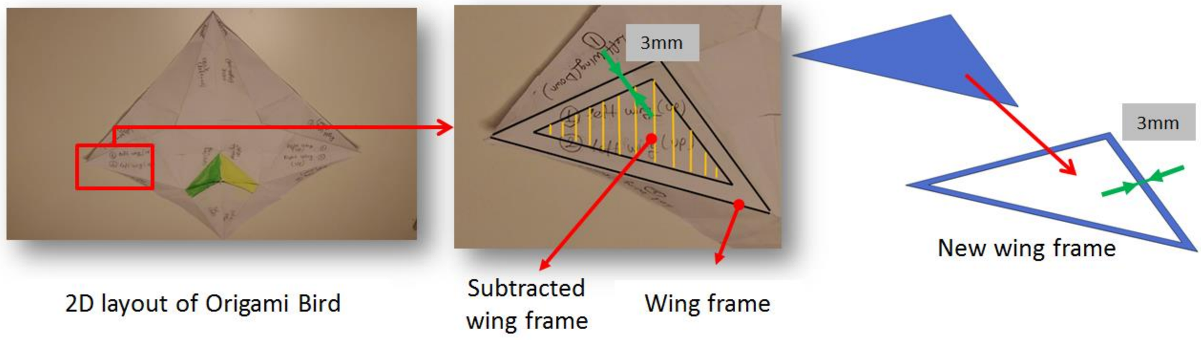

Figure 6: Manufacturing of the Wing

Main frame of the wing is manufactured by subtracting specified area in Figure 6 from 2D layout of origami bird. Different sized 3D printed bars are attached to the wing frame to obtain proper airfoil shape as shown in Figure 7.

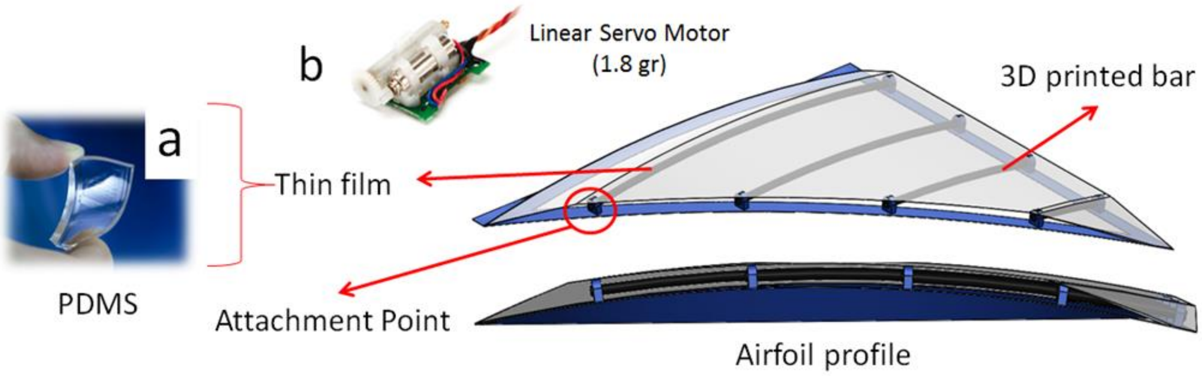

Figure 7: Wing design a) PDMS (What are some new inventions in electrical engineering all the engineers of the related field must be aware of?) b) Servo motor (1.8-Gram Linear Servo)

PDMS [Tanaka et al., 2008; Patel et al., 2008] or Mylar thin film materials are considered as the skin of the wing surface (Figure 7 a). For linear actuation, it is considered to use 1.8 gram linear servo motor as shown in Figure 7 b.

FEA Studies

While designing flapping wing MAVs, wing beat frequency is a crucial factor in terms of structure's dynamical characteristic. Modal Analysis is performed in order to understand proposed MAV's dynamical characteristic. FEA model and mass distribution of model are given in Figure 8 and Table 1 respectively. Servo linear actuator is modeled as a point mass as shown in Figure 8.

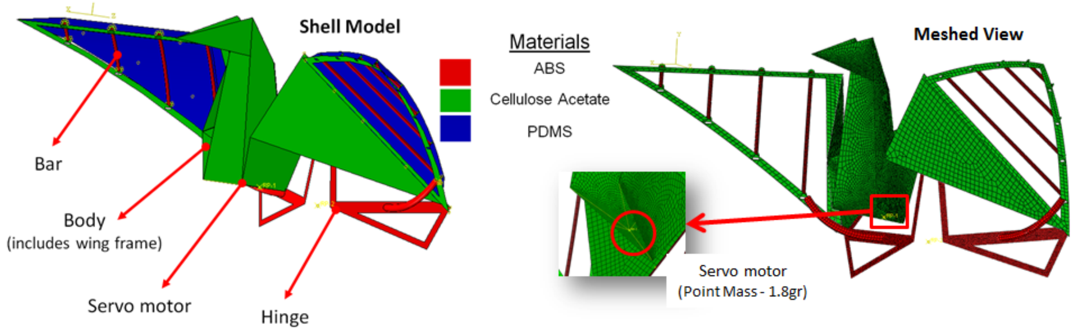

Figure 8. FEA model of the structure

Table 1. Mass distribution

Part		Material	Weight (gr)
Body		Cellulose Acetate	1.15
Hinges (X2)		ABS	2.56
Bars (X8)		ABS	0.3
Servo Motor		-	1.8
Total Mass			5.81

In Flapping Wing Micro Air Vehicle (FWMAV) applications, in order to obtain efficient flapping event, resonant base flapping is preferred. By using this method, inertial effect of wings can be eliminated and maximum lift force and wing oscillation can be obtained with minimum energy. Recently, researchers showed that lift force is maximized by running the system at resonance by real time tests [Zang et al., 2016]. However, for a safe flight, it is desired that while wings are being excited to its natural modes, the body of the structure should not be excited to its natural frequency modes.

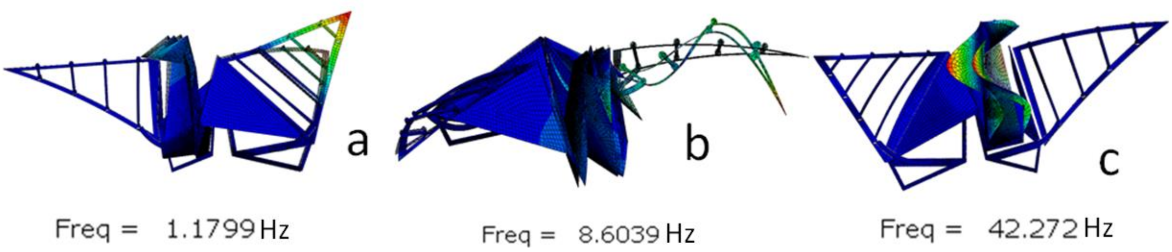

Figure 9: Modal analysis result for the MAV a) First bending mode of the wing b) Second bending mode of the wing c) Body mode

Since wings are subjected to bending moment during flapping motion, bending modes of wings are investigated. The first, second bending modes of the wing and a body mode are given in Figure 9. According to the results, wings are excited in 1.17 Hz and 8.6 Hz wingbeat frequencies. Therefore, in order to obtain maximum oscillation for wings, the user should flap the MAV around these frequencies.

CONCLUSION

In this paper, a novel foldable Flapping Wing Micro Air Vehicle (FWMAV) is presented. The origami-based design method is preferred to reduce the dead-weight of the structure and improve manufacturing related costs and efforts. The body of the proposed FWMAV can be produced by a sheet of cellulose acetate paper, and a low-cost, time-saver manufacturing method such as folding technique and laser-cutting can be utilized. As it is known, the origami structure has monocoque body and wings are actuated with their inherent elasticity of the system. In this framework, the hinge part is developed to emulate elasto-kinematic chain of the original origami bird. PDMS or Mylar thin film materials are considered concerning as the skin of the wing surface. But, in future, depending on implementation issues, the wing section of the origami bird can be cut partially and used as the skin of the wing surface. Commonly, FWMAVs are operated with a particular wing beat frequency to maximize the wing oscillation and lift capacity of the FWMAV. In this regard, modal analysis is employed using ABAQUS CAE (Computer Aided Engineering) software in order to determine the natural modes of wings. According to the FEA result, first bending mode of the wing is approximately 1 Hz. Therefore, the selected servo motor also should perform around desired frequencies.

ACKNOWLEDGEMENT

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