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Controlling The Aerial Posture of a Flapping-wing Micro Air Vehicle by Shifting Its Centre of Gravity

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ABSTRACT

We have developed a Flapping Wing Micro Air Vehicle (FW-MAV) equipped with a mechanism to fly in 2 modes: hovering and horizontal flight. The mechanism consists of a servo motor with battery mounting stay. The battery moves between positions of lying above and below the wings, thereby the centre of gravity (COG) shifts around over the wings. By this feature, the FW-MAV can change the flight posture from aerial-stop posture to the horizontal-flight posture. This flight mode transition was recorded by a high-speed camera and motion capture system.

1. INTRODUCTION

For the purposes of video shooting, search-and-rescue operation, communication, agriculture and environment preservation, various types of Micro Air Vehicle (MAV) have been developed [1-3]. Quadrotor type MAVs enable hovering flight, which is suitable for close surveillance operation. Fixed-wing type MAVs are suitable for long distance flight.

Some missions require the capability to take the two different flying modes, and several ideas have been proposed for this purpose. Green et al. developed a fixed wing airplane which can fly vertically by moving ailerons and elevators [4]. They solved the lack of stability in vertical flight using autonomous software control which is said to be better than a matured pilot. However, it could only keep flying vertically up to 90 seconds.

Flapping-Wing Micro Air Vehicle (FW-MAV) is an alternative solution, since it has the potential to realize both vertical and horizontal flights. Furthermore, the weight scalability, the camouflage ability and the high-mobility flight capacity of FW-MAVs are advantageous and attracting a lot of interests [5]. In our previous study, we proposed a concept to realize both vertical and horizontal flights by changing aerial posture MAV's with the mechanics of centre-of-gravity (COG) shift. [6] Koopmans et al. investigated the applied forces on the flying FW-MAV and the relationship between COG and the flight manner [7]. They further implemented an FW-MAV with a shift mechanism of gearbox position to change the COG, and thus the FW-MAV takes the ability of vertical and horizontal flight modes.

In this paper, we demonstrate a new FW-MAV named "Wifly" equipped with a simple mechanism to change the areal posture. This paper is organized as follows. Section 2 elaborates on the overall design of "WiFly." In Section 3, we will explain the mechanism of COG shift to change the aerial posture. Sections 4 and 5 shows the motion capture analysis to quantitatively evaluate the effect of the COG shift mechanism.

2. OVERVIW OF "WiFly"

Figure 1 shows an overall picture of WiFly, which comprises of a gear box, flapping wings, tail wings,

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tail rotor, micro-computer chip for controlling actuators and Centre of Gravity Shift (COGS) mechanism. Figure 2 shows a dimensional outline drawing together with components layout. The components are settled on a frame made of carbon-fiber shafts. Four carbon-fiber shafts are arranged in parallel to form a rectangular cross-section frame. The COGS mechanism is settled on the upper side of the wings, across the centre of which the lithium polymer battery pass through. To optimize the weight balance in the hovering mode, the gearbox is installed as it is shown in Figure 1 so that the wings are set on the bottom side of the frame. We employed "Lazurite Fly" as the control circuit board. This is a prototype product offered by LAPIS semiconductor Co., Ltd. It is equipped with several sensors and communicates with a controller via a 920 MHz wireless connection. The tail rotor adjusts the yaw moment by pushing the tail right or left. The body weight including the battery weighs only about 32 g.

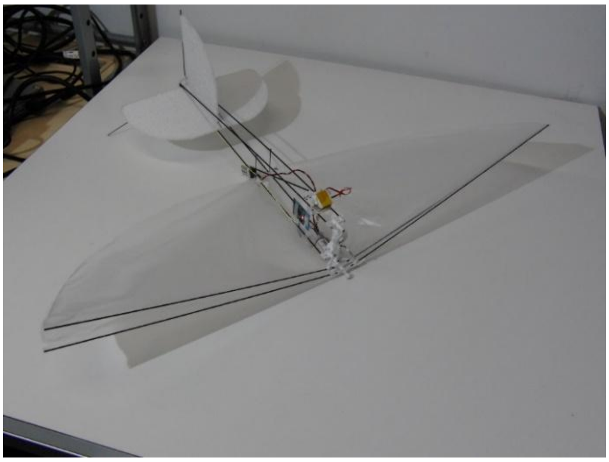

Figure 1 - WiFly

Weight	32g
Wing span	62 cm
Frame length	39 cm
Battery	3.7 V LiPo battery

Table 2 – Specifications of WiFly

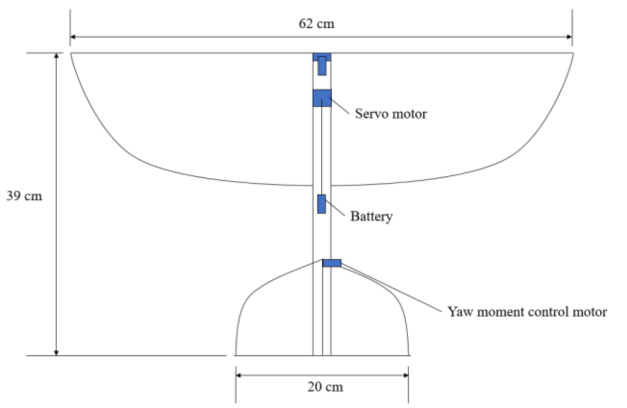

Figure 2 – Dimensional outline of WiFly and components arrangement

3. COGS MECHANISM

The appropriate positioning of COG is the key to stabilize the aerial posture of FW-MAV like those of normal aircrafts. This is true not only in the horizontal flight, but also in the hovering flight. The COGS is realized by the change in the mass distribution in the FW-MAV. Koopmans et al. developed a FW-MAV with a function to change the aerial posture by sliding the wing and gearbox, which are the heaviest parts in the FW-MAV [7]. The slide mechanism was realized by modifying a micro linear servo motor.

In our developed COGS mechanism, the battery is swinged between above and under the wings, and it realizes the seamless change between hovering flight and horizontal flights modes.

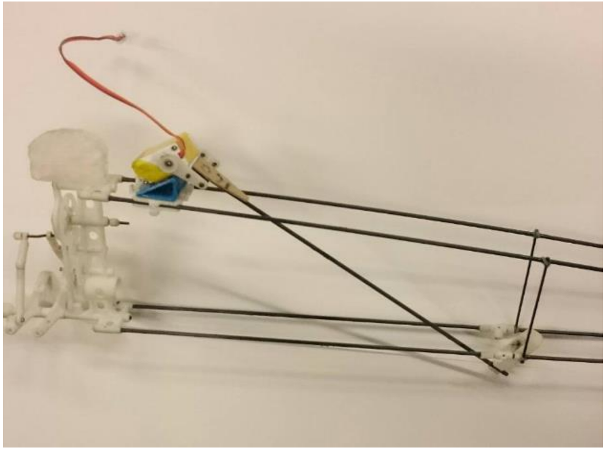

Figure 3 - The CPGS mechanism

Figure 3 shows the COGS mechanism. The servo motor rotates 75 degrees, and the battery moves vertically across through the carbon-shaft frame. Figure 4 shows the definition of internal axes of WiFly. The components are arranged symmetrically the z-x plane, so that the COG moves in this plane. We measured the trajectory of COG transition by hanging the FW-MAV from different points. Figure 5 shows the photos of the hanging measurement, and the obtained COG trajectory is shown in Figure 6. As indicated in Figure 6, the COG shifts to above the wings and backward, as the servo motor rotates from 0 to 75 degrees.

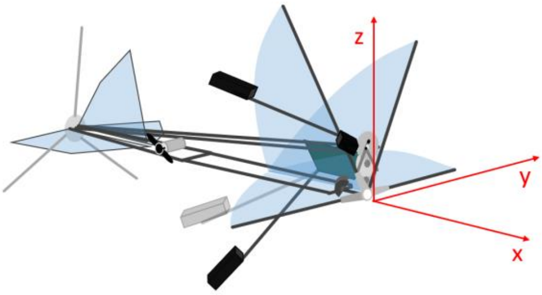

Figure 4 - Definition of internal axes of WiFly

Figure 5 - images of hanging experiments to measure COG

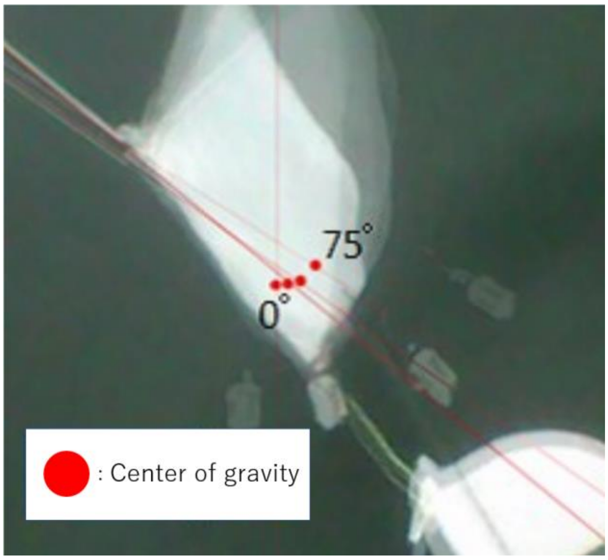

Figure 6 - The range of COG motion

4. FLYING EXPERIMENTAL

To demonstrate the effect of the COGS mechanism, we performed motion-capture experiments. Figure 7 shows an image of the experiments. The flight area is 6 x 5 meters in depth and width, and about 3.5 meters in height. We recorded the trajectory from the taking off from a vertical starting position into the horizontal flight. The WiFly was set about 30 cm above the floor in order that the motion-capture system can track the taking off. Detection/tracking markers were stuck on the gearbox and tail wing.

Figure 7 - Actual image of motion-capture Experiment

In the second experiment, we recorded the horizontal flight. The detection markers were placed on the same positions as the first experiment. WiFly was launched from hand with about 45 degrees pitch angle, stand-bying with the flapping motion on the hand. The flapping power is fixed at about 80 % of the maximum, which is the best condition to keep the stable horizontal flight. This percentage was the best-practice to keep the stable horizontal flight.

5. RESULTS AND DISCUSSION

Figure 8 shows a series of photos taken by high-speed video recording in which WiFly changed its flight posture. In the first and second shots, the battery is shaded by the wings because it is located above the wings. In the third and fourth shots, the battery swung down and can be seen in photos and the posture is changed. Figure 9 shows the recorded trajectory and areal posture by the motion capture system in the sequence of the take-off, hovering flight and horizontal flight. The coordinate is shown in meter scale. WiFly successfully took off, moved forward slightly and then continued ascending while shaking its tail. After it arrived at the peak altitude, the flight mode is changed into horizontal. WiFly once lost altitude just after the shift of the flight posture, because flapping power is temporarily suppressed. This operation is required to switch the flight modes. Figure 10 shows a trajectory of a hovering flight of about 14 seconds. WiFly kept the constant altitude slightly with a periodic swaying motion. The swaying motion induces the undesired horizontal migration. The swaying motion can be cancelled by yaw control rotor, which is left for future work.

Figure 11 shows a trajectory of horizontal flight . Some data points are dropped, where the motion capture failed to track the position of a few markers. Just after the launch, WiFly was accelerated ahead as it bows downwards slightly. As it gained speed, the trajectory is gradually elevated.

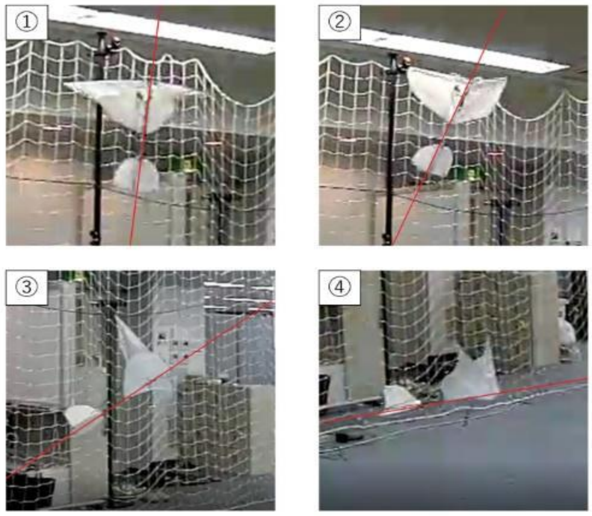

Figure 8 - Sequence of images of transition from vertical posture to horizontal posture

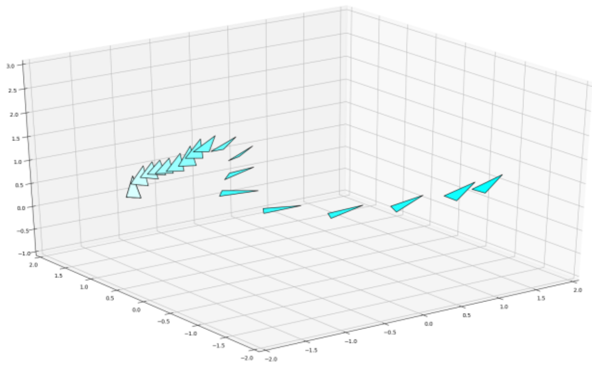

Figure 9 - Trajectory of a navigation from the taking-off to horizontal flight

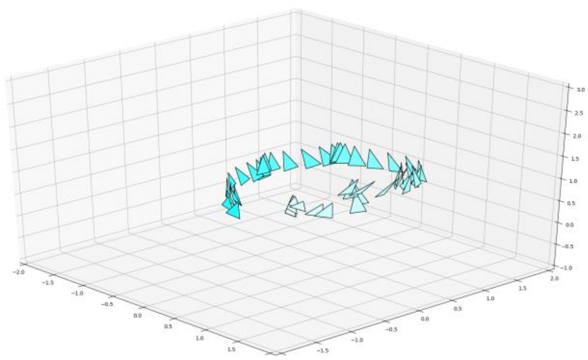

Figure 10 - Trajectory of a hovering flight

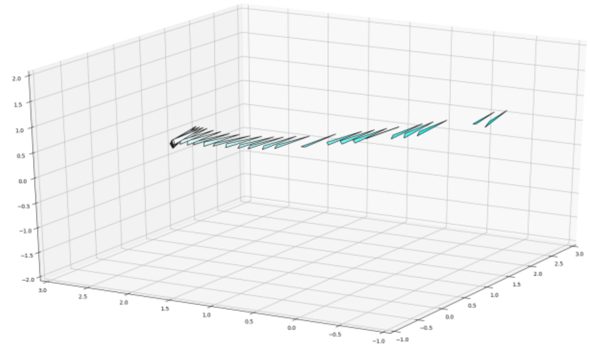

Figure 11 - Trajectory of a fast forward flight

5. FUTURE WORK

The periodical swaying motion during hovering flight shown in Figure 10 is undesired, because it sometimes causes the FW-MAV to lose the balance. This motion could be cancelled by the yaw-moment control rotor. Furthermore, it is urgently required to implement a flight assistance program to change the flight modes, because flapping power and the angle of servo should be controlled precisely at the same time.

6. SUMMARY

We have developed a flapping wing MAV with a mechanism to shift the centre-of-gravity, which comprises a servo motor and battery mounting stay. It moves the battery between lying above and below the wings. It was demonstrated by motion capture experiments that the MAV took-off vertically and hovered at a constant altitude, and successfully changed the aerial posture into horizontal flight.

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