Application of Japanese Origami Ball for Floating Multirotor Aerial Robot

P. H. Le, J. Molina, and S. Hirai

***Abstract*—**In this work, we propose the application of Japanese "Origami" art for a floating function of a small aerial vehicle such as a hexarotor. A preliminary experiment was conducted using Origami magic balls mounted under a hexarotor. This magic ball can expand and shrink using an air pump during free flying. Using this interesting and functional concept, it promises to reduce the resistance of wind as well as reduce the energy consumption when the Origami balls are deflated. This approach can be particularly useful in rescue emergency situations. Furthermore, there are many unexpected reasons that may cause the multi-rotor has to land on the surface of water due to problems with the communication between the aircraft and the ground station. In addition, a complementary experiment was designed to prove that the hexarotor can fly maintaining the stability and also, takes off and lands on the surface of water using air balloons.

***Keywords*—**Helicopter, Japanese Origami ball, Floating, Aerial Robots, Rescue.

I. Introduction

DISASTERS, such as earthquake and tsunami occur suddenly with terrible consequences, often unforeseen despite today's advanced technologies. Japan often experiences annual earthquakes; the large earthquake in March, 2011 caused more than 15,000 deaths, with over 90% due to the accompanying tsunami [1, 2]. Thus, search and rescues techniques employing aerial robots are urgently demanded.

In recent years, the research interest in aerial robotics has been grown due to their multifunctional characteristics. The earliest novel robot design is the "Multi-field Universal Wheel for Air-land Vehicle" which can fly in air, float on water, and roll on the ground by means of a life ring mounted on the quadrotor [3]. These capabilities indicate that the robot is ideal for rescue efforts, however, the resistance of wind acts the area of the life ring causing instability during flight. In addition, the aircraft require a large amount of energy to carry itself. Another research group developed an autonomous blimp-type robot system for rescue [4]. When the robot system is flying in a closed environment or in a light wind, it is possible to move it spatially using computer control. However, small blimps in this robot system are usually uncontrollable in windy conditions owning to the lack of propulsive force against the wind flows.

In our study, we investigate the function of the Japanese art of folding paper, which is called "Origami", with applications to aerial robotics. There is a lot of interesting paper designs in the research of the Japanese computer scientist, Jun Mitani [5]. He has been studying algorithms and user interfaces for generating 3D shapes in a computer. Using the art of folding pieces of paper to create shapes is an appealing concept for robotics. This means that two dimensional materials can be transformed into three dimensional structures that are inherently flexible, and deformable. Structures that can be folded and unfolded enable all kind of interesting functions that otherwise would only be possible with systems more complex [6, 7]. The newest approach can be particularly useful in Origami-inspired to design wheels for mobile robots that allow them to be nimbler and stronger [8]. In particular, our research focuses on aerial robots and how to use the Origami art for the purpose of floating on the water.

The idea has come by using Origami method; some kinds of magic balls will be made and attach them to each arm of a hexarotor. It is called a "magic" ball due to its shape can be changed when it is picked up and handle. These balls can be folded during flying and pumping air expands the balls when the aircraft is landing on the water. Small sized magic balls and their main characteristic that allow them to become bigger or smaller promise to solve the problem of resistance to the wind and energy consumption.

There are several motivations for this study. Firstly, small aerial robots equipped with rescue equipment can travel far from the ground station and respond quickly to emergencies. For example, consider people unable to swim in a natural disaster, aerial robots can provide life rings to the people at risk. Secondly, rescue safety and effectiveness are important. Finally, unexpected mistakes such as a communication failure may suddenly occur during flight above the water potentially leading to a crash. Thus, an emergency system allowing helicopters to land on water must be considered.

The remainder of the paper is organized as follows. Section II gives a brief introduction of a commercial multi-rotor helicopter which is used in this experiment. Section III provides an explanation of the Origami method for a floating hexarotor. The initial testing of the magic balls mounted under the helicopter and the performance of a floating aircraft on the water are shown in section IV. Finally, some conclusions of the present work together with some ideas for the future research are given in section V and VI respectively.

II. Description the Multi-Rotor

A. Helicopter Platform

In this research, a commercial multi-rotor helicopter DJI F550 was used. The DJI F550 is a helicopter with six rotors. The size of the diagonal wheelbase is 550 mm and the maximum payload capacity is about 1200 grams [9]. This

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helicopter uses six 15A ESCs (Electric Speed Controllers) and six 920kV motors. The battery is of 3300 mAh and six propellers of 10x3.8 inch. The overall assembly is shown in Fig. 1.

Fig. 1 Completely assembly of the DJI F550 Hexarotor

B. Flight Controller

Fig. 2 shows the DJI Naza - M Lite flight control system. The flight controller is all-in-one supporting six types of multirotors. It contains 3-axis gyroscope, 3-axis accelerometer and barometer in its main controller. It can measure the flying altitude and attitude; therefore it can be used for autopilot and automatic control. It can also use a GPS (global positioning system) which allows the accurate determination of the position and altitude in windy conditions. The hovering accuracy is approximately 2.5 m horizontally and 0.8 m vertically [9].

Fig. 2 DJI NAZA Flight Controller

III. ORIGAMI BALL METHOD

Origami is the Japanese art of folding paper into different shapes. An Origami magic ball is specially designed sphere created by folding from a piece of paper. This model is employed to develop a practical floating system for aerial robots. Some Origami balls are attached to the helicopter's frame and inflate or deflate by means of a mini air pump.

From the tutorial, "How to make and Origami magic ball" [10], as shown in Fig. 3, we begin with a sheet of 500 x 250 mm paper with a dimensional ratia of 1:2. The thickness of one sheet is approximately 0.1 mm. According to instructions, the paper must be folded along the long side into 32 equal parts by repeatedly folding it in half -using genderless folds.

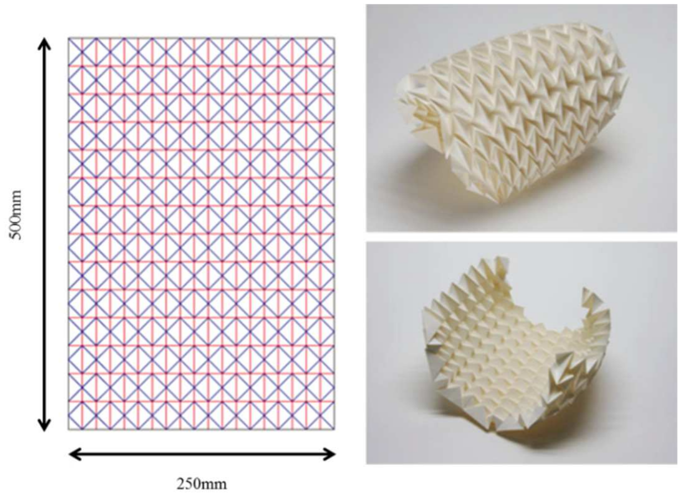

Fig. 3 A 500×250mm paper for folding ball [10]

The magic ball can be deformed in this case from the minimum vertical length of 30 millimeters (Fig. 4] to the maximum diameter of 100 millimeters (Fig. 5]. Because it can be turned in a small dimension, this Origami model could be ideal for applications where the resistance of wind plays an important role. This is one of the most important issues for the future work.

Fig. 4 Real size of the deflated ball

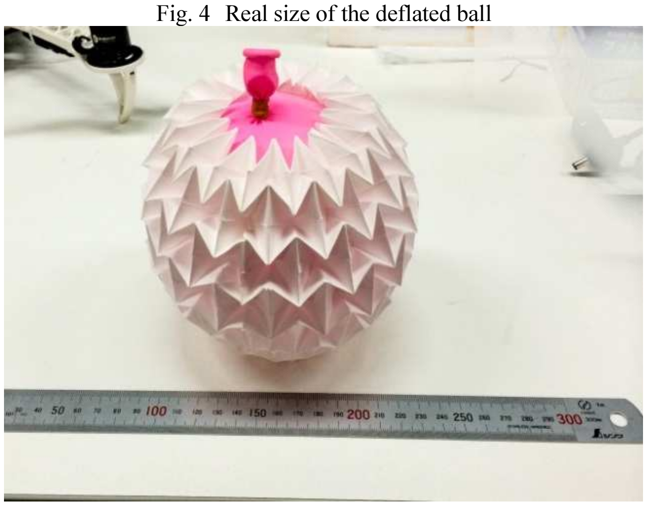

Fig. 5 Real size of the inflated ball

IV. EXPERIMENTS

A. Indoor Test

For the initial test, a small air pump was mounted under the center of DJI 550 frame. This air pump is connected to the four Origami balls using four rubber hoses (Fig. 6) with the specifications of that air pump shown in Table I. These Origami balls are attached under the arms of the hexarotor as is showing in Fig. 7. The flight test was performed indoors and it consisted of taking off and after a while, starts pumping air to the origami balls to observe the system changing the balls from the smaller size to the bigger size (Fig. 8]. However, relationship between the thickness and the dimension of the sheet paper for folding the Origami ball is an important factor for folding/unfolding process of the Origami ball.

TABLE I
SPECIFICATIONS OF THE AIR PUMP

DC Input voltage	12 V
Power	20 W
Pressure	0.51 Psi
Weight	245 g
Size	Height = 110mm, width = 85mm, length = 105mm

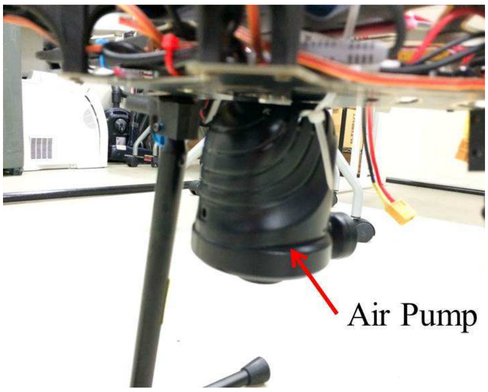

Fig. 6 The small air pump mounted under the center of frame

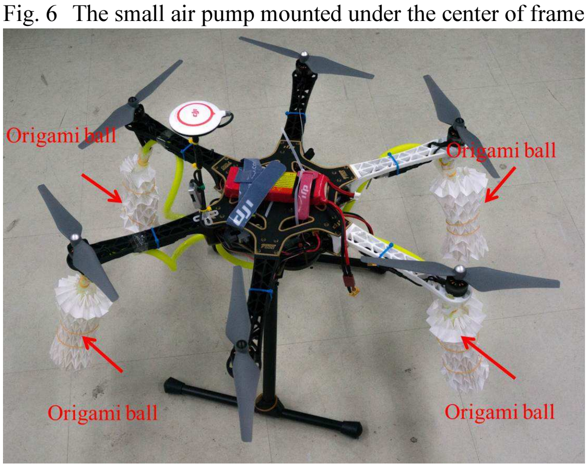

Fig. 7 Deflated Origami ball while the helicopter in on the ground

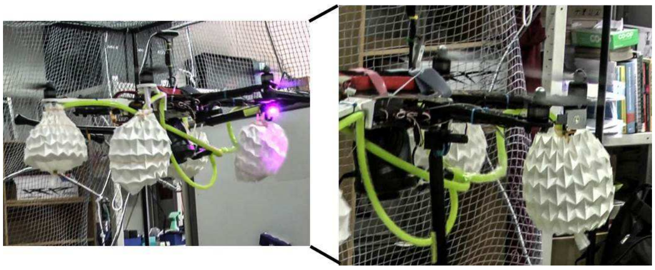

Fig. 8 Deflated Origami ball while the helicopter takes off and flies

B. Outdoors Test

Before applying the magic balls in a real situation, the helicopter has to be tested in order to know whether it floats or not. For this experiment, four normal air balls and a set of three small gum balls were mounted in the DJI F550. The test was developed outdoors with a wind speed of 18 km/h. The helicopter can flight and also land on the water successfully as shown in Fig. 9. In addition, when the helicopter has landed on the water, it looks unbalanced due to the unequaled ball size. It suggests that the air-pumping control in the Origami balls is necessary for the future work. Fig. 10 shows that the hexarotor carrying out these balls can take off smoothly from the water.

Fig. 9 Successful test of the floating hexarotor with the air balloons and landing on the water

Fig. 10 Successful test of taking off of hexarotor from the water

V. CONCLUSION

In this article, a new concept of Japanese Origami art for a floating helicopter has been presented. In particular, the structure of "Origami" magic ball was introduced and an initial test was performed using a DJI F550 hexarotor. The Origami magic balls were attached under the helicopter and those were inflated and deflated by means of a small air pump meanwhile the helicopter was flying indoors. In addition, an outdoor experiment where the hexarotor flies with normal air balls was also conducted. The helicopter could perfectly take off and land on the surface of water and was able to maintain the stability during the complete flying. This experiment proves that it is possible to use law-cost flight controller and attach some elements whose shape modified the structure of the frame and still remains stability during flying.

VI. FUTURE WORK

The initial implementation of the Japanese origami balls for the floating helicopter showed experimently that the concept is feasible. In the future work, we need to perform the experiments for a floating helicopter system using water proof origami paper. A mini air pump has also to be used. Additionally, the effect of the resistance of the wind has to be studied in detail.

ACKNOWLEDGMENT

This work is partially supported by "Industry-Academia Cooperative Program for the Development of Advanced Human Resources" the Japan Society for the Promotion of Science for Postdoctoral Fellow.

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