Synthesis of Drive Systems of Flapping and Feathering Motions for Bird-like Robot using Twist Drive Mechanism

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Abstract

In the research field of flying robots, many studies on flapping-wing aircraft have been conducted in recent years. In our previous research, we have developed a robot that mimics the musculoskeletal structure of an actual bird using a twist drive mechanism, and have achieved two types of wing motions, which are flapping and feathering, independently of each other. In this study, we have synthesized the drive systems of flapping and feathering, and have succeeded to interlocked two motions. In addition, we have covered the wings with a membrane to verify the wing motion under the condition of a membrane wing, which is strongly affected by air resistance. The flapping motion with twisting of the hands, such as actual birds do in flight, has been achieved.

Keywords: Twist Drive, Flapping robot, Feathering robot, Biomimetics

1. Introduction

Currently, a lot of research in the field of flying robots is focused on rotary-wing aircraft such as drones. These aircrafts use propellers attached to the fuselage to generate lift for flight, and are used in a wide variety of fields in our daily lives, such as transportation [1] and aerial photography [2]. Flying robots that differ from rotary-wing aircraft include fixed-wing aircraft and flapping-wing aircraft. Fixed-wing aircraft include airplanes which already play important roles in our daily lives as same as rotary wing aircraft. On the other hand, flapping-wing aircraft have been the focus of attention in recent years, but compared to the two types of flying robots mentioned above, there are still few examples of research and very only a few examples of use.

Flapping-wing robots mainly imitate the motions of actual flying creatures, such as birds and insects. In this research, we focus on a bird-like flapping wing aircraft. In research on bird-like robots, most of them use crank mechanisms or servo motors in the body of the robot to achieve the wing motion. The crank mechanism converts the rotational motion of the motor into the swinging motion of the wings via gears. In the case of servo motors, the wing is directly attached to the rotary shaft of the servo motor, and the angle of rotation of the servo motor is adjusted to achieve the swinging motion of the wing. However, actual birds move their wings by contracting and relaxing their muscles, and the mechanisms of the above two types of mechanisms are very different from those of actual birds. Therefore, in this study, we focused on the imitation of the bird's motions by employing the twist drive mechanism [3].

The twist drive mechanism utilizes the tensile force generated when twisting a thread. As shown in Fig.1, the rotating shaft of the motor is connected to the object to be moved by a thread, and rotating the motor causes the thread to twist and contract, pulling the object. Rotating the motor in reverse causes the thread to untwist, weakening the pulling force. The feature of being able to control the movement of an object by contraction and relaxation of a thread is very similar to the actual muscular motion of a bird. In our previous research [4], we have developed a robot that mimics the musculoskeletal structure of a real bird using a twist drive mechanism, and confirmed that flapping can be achieved. In addition, birds perform various wing motions in flight in parallel with flapping, such as feathering. Feathering is a twisting action of the wing tip hand, and has the role of increasing lift and thrust in flight and reducing aerodynamic resistance by changing the angle of attach. In our research [5], we tried to achieve feathering in addition to flapping by using a twist-drive mechanism, and succeeded in developing a robot that can achieve the two types of motions independently.

In this paper, we integrate and link the flapping and feathering drive systems, which were independently achieved in the literature [5], to realize a flapping motion with a twisting motion of the hand part, as actual birds do in flight. Next, a membrane is attached to the wing, and the motion is verified under the condition of a membrane wing, which is strongly affected by air resistance.

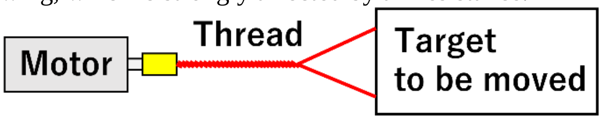


Fig.1.Twist drive mechanism

2. Achievement of flapping with feathering

2.1. *Interlocking flapping and feathering drive systems*

A CAD drawing of the developed flapping wing robot is shown in Fig.2. Regarding the motors used in the twist drive mechanism, two ECX SPEED 13M brushless motors made by Maxon were used for flapping, and two geared motors made by Pololu were used for feathering [5]. Motors for flapping are controlled using the MAXON EPOS4 Compact50/5 control unit with Windows PC. Motors for feathering are controlled using the Arduino Uno and the TA7291P motor drivers.

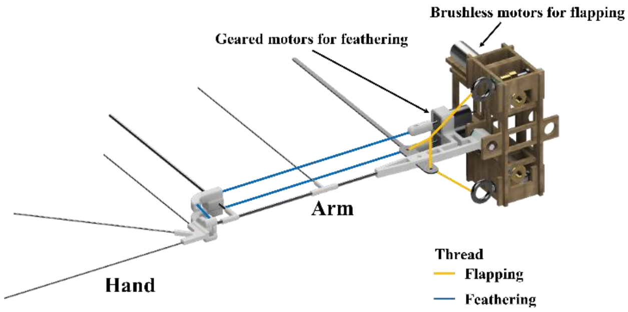


Fig.2.CAD model of the developed flapping wing robot

The wings of the flapping wing robot are divided into arm and hand sections, and only the hand parts are moved for feathering. Two motors of the twist drive mechanism for feathering are fixed at the base of the wing, and two motors for flapping are fixed inside the body of the robot. Focusing on the parameters of the wing only, the wing length is 380.00 mm, the wing chord length is 161.00 mm, and the wing weight, including the weight of the two motors for feathering, is 29.94 g. Fig.3 shows the developed flapping wing aircraft flapping and Fig.4 shows feathering. The flapping frequency for flapping was 1 Hz, and the maximum angle for both swinging up and down was 34 °. Fig.4 shows the image of twisting the front edge of the hand (the front side of Fig.4) in the upward and downward directions. The direction of the front edge of the hand can be switched to the upward and downward directions in as little as about 0.13 seconds.

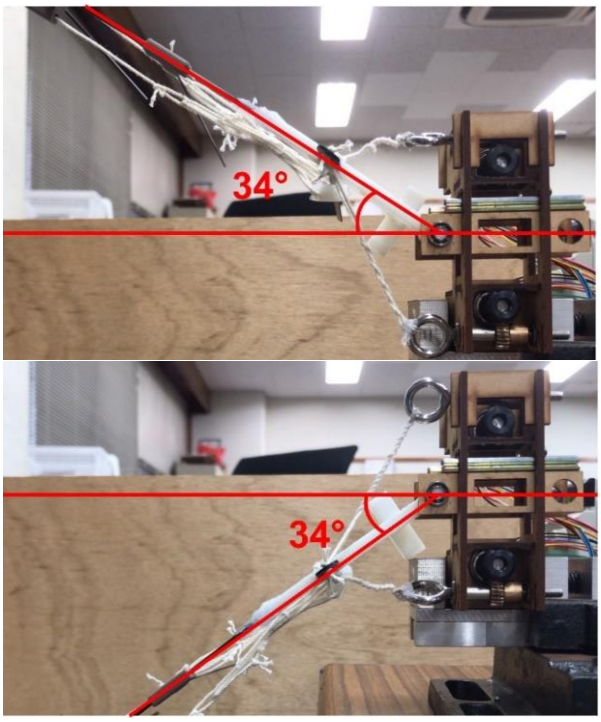


Fig.3.Flapping in progress

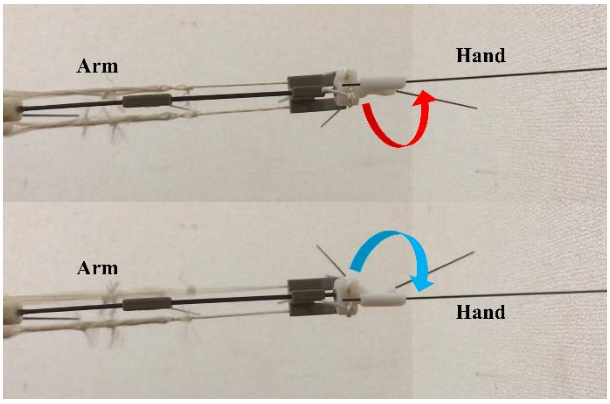


Fig.4.Feathering in progress

In our previous research [5], each operation in Fig.3 and Fig.4 was performed separately. In this research, we tried to achieve a combined flapping and feathering motion by linking the drive systems of the flapping and feathering motions through serial communication. Referring to the actual flapping behavior of birds, we decided that the timing of feathering when combining the two types of motion should be performed at the moment when the wings switch between flapping up and down. The flow of the program is as shown in the flowchart in Fig.5. First, immediately after the wing is swung up, the values for twisting the front edge of the hand in the downward direction are sent to the Arduino Uno via serial communication. Then, immediately after the wing is swung down, the values for twisting the front edge of the hand in the upward direction are sent to the Arduino Uno via serial communication in the same manner. The above process assumes that the front edge of the hand turns upward while the wing is being swung up, and that the front edge of the hand turns downward while the wing is being swung down. By repeating the process in a series of steps, we aimed to achieve flapping with feathering.

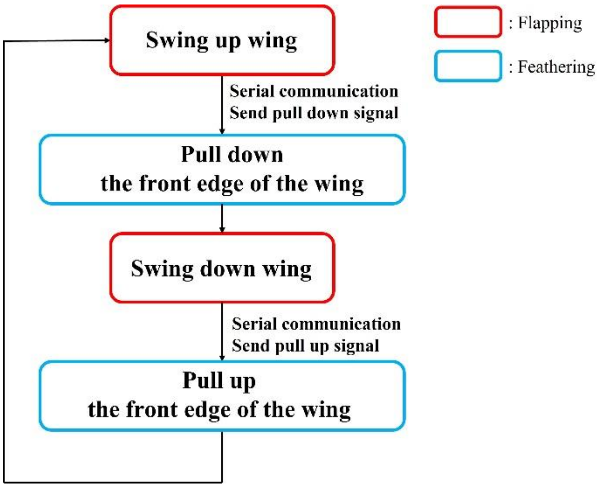
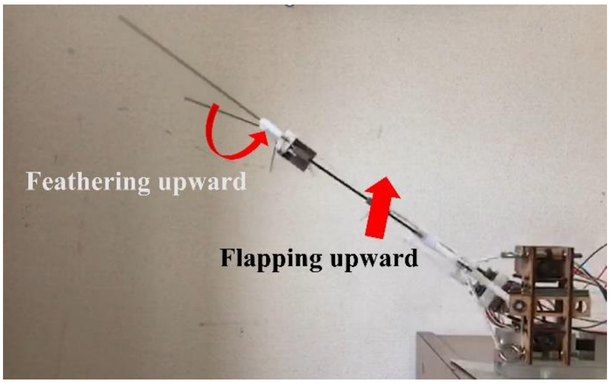


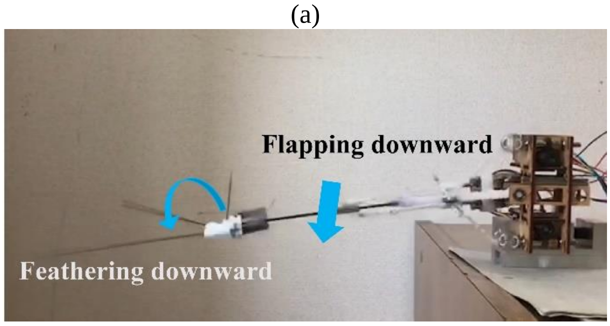
Fig.5.Program flowchart for linking flapping and feathering

2.2. *Operation verification results*

A program according to the flowchart in Fig.5 was created and the operation was verified. Fig.6(a) shows the hand part while swinging up the wing, and it was confirmed that the front edge of the hand part was turning upward. Similarly, Fig.6(b) shows the hand with the wing swinging down, and it was confirmed that the front edge of the hand was turning downward. Thus, we have succeeded to link each drive system of flapping and feathering using serial communication.



(a)



(b)

Fig.6.View of the hand section when the wing is flapping up and down

3. Verification of Operation with Membrane Wing

3.1. *Membrane Attachment to a Skeleton Wing*

In the operation verification in Section 2, the wing of the flapping-wing aircraft was only the frame, and the effect of air resistance was very small. Since the flapping wing machine is a flying robot, achieving autonomous flight is one of its future goals. Therefore, it is necessary to have wings that can generate lift and thrust, which are important for flight, and that can flap even under the condition of high air resistance. Therefore, in this study, we attached a membrane to the wing and verified whether flapping and feathering are possible even when the wing is strongly affected by air resistance. Fig.7 shows the flapping wing aircraft with the membrane attached. Ripstop fabric was used for the wing membrane. The wing membrane is attached only to the upper surface of the wing, and the hand and arm parts are separated at the joints so as not to interfere with feathering. The weight of the membrane wing, including the weight of the two motors for feathering, was 32.90 g, an increase of 2.96 g from the skeleton wing state in Section 2.

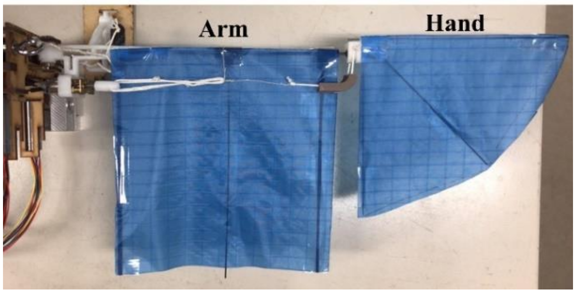
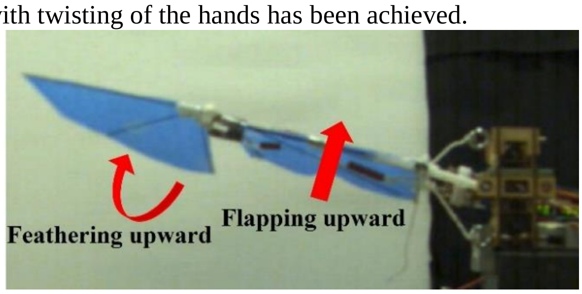


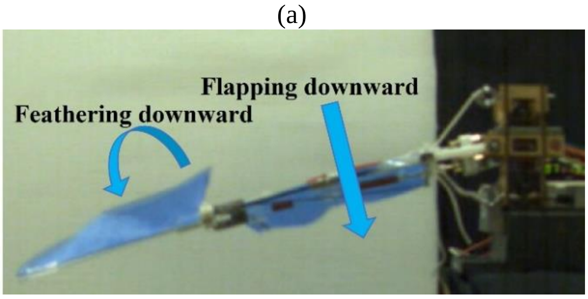
Fig.7.Flapping wing aircraft with membrane on the wing

3.2. *Operation verification under membrane wing*

Fig.8 shows the results of the operation verification in the state shown in Fig.7. Fig.8(a) shows that the front edge of the hand is turned upward while the wing is being swung up. Similarly, Fig.8(b) shows that the front edge of the hand was intentionally directed downward while the wing was being swung down. The flapping motion with twisting of the hands has been achieved.



(a)



(b)

Fig.8.View of the hand section when the membrane wing is flapping up and down

4. Conclusion

In this paper, we have linked the flapping and feathering drive systems to achieve flapping motion with feathering. We have also verified the operation of the membrane wing, which is strongly affected by air resistance, and have confirmed that it performs as well as the skeleton wing. Our future work is to measure lift and thrust forces of the membrane wing.

Acknowledgements

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Authors Introduction

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