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Production of a Tilt Rotor System and a Speed Control of a DC Motor for Quadrotors

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***Abstract*— Unmanned Aerial Vehicles (UAVs) have been researched as a means of collecting information during disasters. Among them, VTOL UAVs that are called Quadrotor, have been attracting attention. A Quadrotor has a superior maneuverability than other UAVs. However, it is inferior to fixed-wing type UAVs in flying speed and cruising range. When UAVs are used for extensive disasters such as earthquakes, it needs to collect widespread information. Therefore, this research is aimed at developing a Quadrotor that can realize high-speed flight and wide cruising range by mounting a tilt system on the rotors in the conventional Quadrotor. This paper presents the overview of the new Quadrotor suggested in this study and describes the production of a tilt system attached to the conventional Quadrotor. Then, some experiments are conducted to check the fundamental operation of the tilt system. In addition, the overview of the PD control is also described for the speed control of a DC motor.**

***Index Terms*— UAV, Quadrotor, tilt rotor system, PD control.**

I. Introduction

In recent years, Unmanned Aerial Vehicles (UAVs) have been studied as means of collecting information during disasters [1][2]. UAVs are usually divided into two types: a fixed-wing type and a rotary-wing type. Fixed-wing type UAVs have a high flying speed and a wide cruising range, however, they need wide spaces to take off and land. Rotary-wing type UAVs can take off and land without wide spaces. In addition, they can hover. Such hovering is good means to collect information by taking pictures from the air. However, they have lower flying speed and shorter cruising range than fixed-wing type UAVs. Vertical take-off and landing (VTOL) type UAVs that are called "Quadrotor" have been attracting more attention than other rotary-wing type UAVs. Quadrotors are superior to other UAVs in maneuverability [3]. They can control their movement and attitude by changing the revolution speed of their rotors. Fixed-wing type UAVs and rotary-wing type UAVs are usually used depending on an objective on each respective advantage. However, during disasters like earthquakes, widespread information must be collected rapidly. Then, a UAV which has high flying speed, wide cruising range and a hovering ability is demanded.

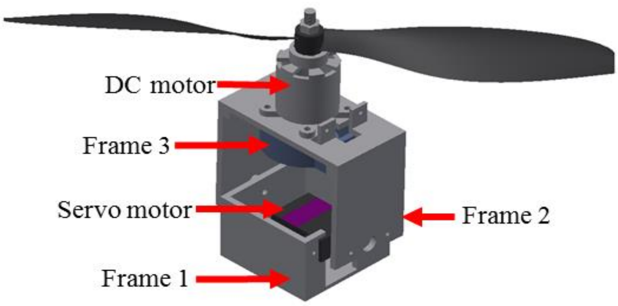

Fig. 1. Drawing of a tilt rotor system

Therefore, tilt rotor aircraft are being studied. They are classified as VTOL type aircraft. They can change from a vertical flying mode to a horizontal flying mode by tilting rotors. Presently, tilt rotor aircraft of the structure having two rotors are often being used like Ospreys manufactured by Boeing[4][5]. However, such tilt rotor aircraft have a problem that their stability is decreased when changing their flying mode. This is because their upward thrust is rapidly decreased when changing the angles of rotors.

In this research, the objective is to develop a new Quadrotor by attaching a tilt rotor system on each rotor in a conventional Quadrotor. This new Quadrotor can be expected to realize a high-speed flight, a wide cruising range and a hovering ability. In addition, it realizes also a good maneuverability and stability. This paper describes the tilt rotor system attached to a conventional Quadrotor. In addition, the overview of the PD controller and some experiments are also described for the revolution speed control of a rotor. Finally, the overview of the new Quadrotor suggested in this study is presented.

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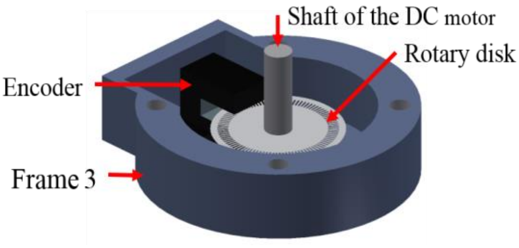

Fig. 2. Inside structure of the frame3

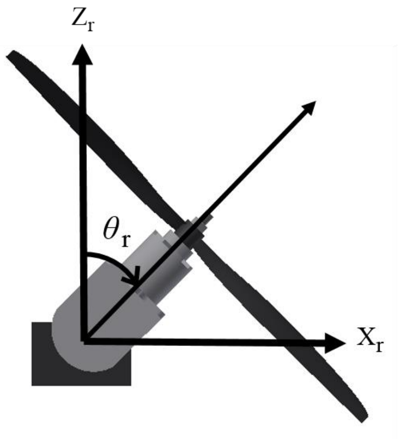

Fig. 3. Coordinate of a tilt rotor system

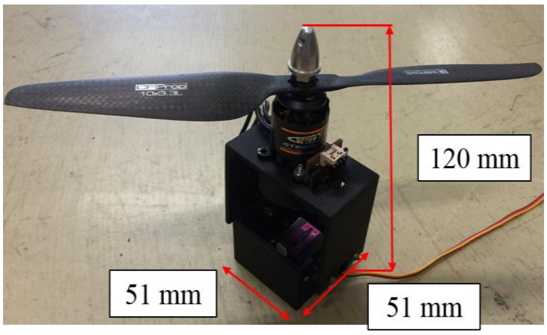

Fig. 4. Appearance of a tilt rotor system

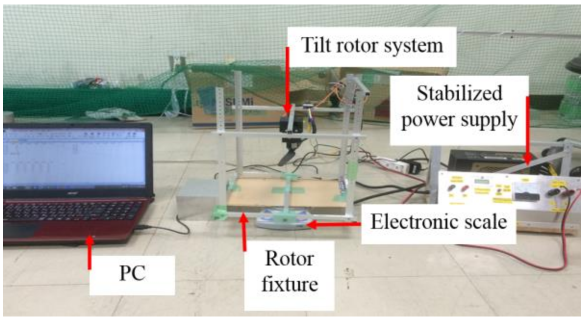

Fig. 5. Setup for the experiment

II. Outline of a Tilt Rotor System

A. Drawing

The drawing of a tilt rotor system is shown in Fig. 1. The tilt rotor system consists of a frame 1, a frame 2, a frame 3, a servo motor and an encoder. The frame 1 is the main body part of the tilt rotor system. The frame 2 is a table to fix a rotor. It is driven by a servo motor. The servo motor can control the angle of a rotor. The frame 3 is a cover of an encoder. The encoder cannot work correctly, if there are lights. Therefore, the frame 3 prevents lights from disturbing the encoder by covering it. Fig. 2 shows the inside structure of the frame 3. The encoder is fixed to a frame 3. A rotary disk for the encoder is fixed to the shaft of the DC motor.

B. Definition of Angles for the Coordinate System

Fig. 3 shows the definition of angles of a tilt rotor system in the orthogonal coordinate system. X_r is defined as the positive direction of the horizontal, whereas Z_r is defined as the positive direction of the vertical. Tilting angle of a tilt rotor system is defined as θ_r.

C. Appearance of a Tilt Rotor System

Fig. 4 shows the appearance of the tilt rotor system. The frame 1, the frame 2, and the frame 3 are manufactured from ABS resin by using a 3D printer. The completed tilt rotor system is 51 mm in length, 51 mm in width and 140 mm in depth. It weighs approximately 166 g, including a DC motor and a propeller.

D. Fundamental Operations

The tilt rotor system can control the own angle by using the servo motor. It has the operating range of 90 degrees. Then, this system can generate thrusts depending on its angle. The vertical thrust T_v generated by the tilt rotor system is calculated by using the thrust of the rotor T and the angle of the rotor θ_r in Eq. 1.

$$T_v = T\cos\theta_r \qquad (1)$$

In addition, this system can measure the revolution speed of its rotor by using its encoder.

III. Control of the Revolution Speed of the Rotor

A. PD Controller

In this research, a PD controller is used to control the revolution speed of a rotor. Defining the revolution speed of a rotor as ω, the time derivative of ω as $\dot{\omega}$, the target value of the revolution speed as ω_d, the P gain as K_p, the D gain as K_d, and the control input as U, the controller for the revolution speed of the rotor is described by

$$U = K_p(\omega_d - \omega) - K_d\dot{\omega} \qquad (2)$$

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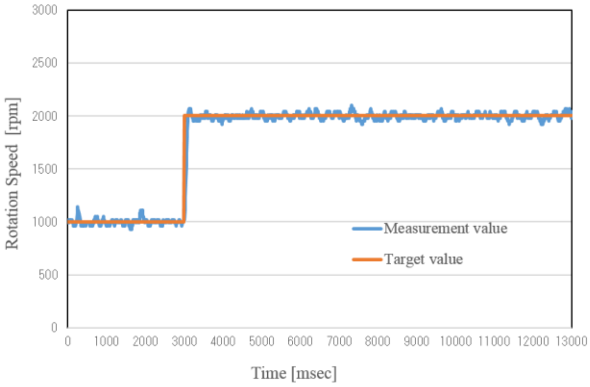
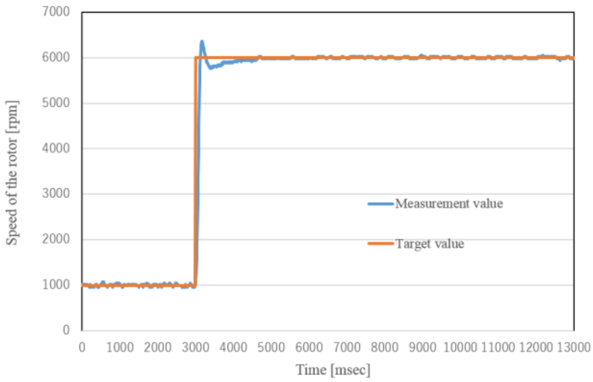
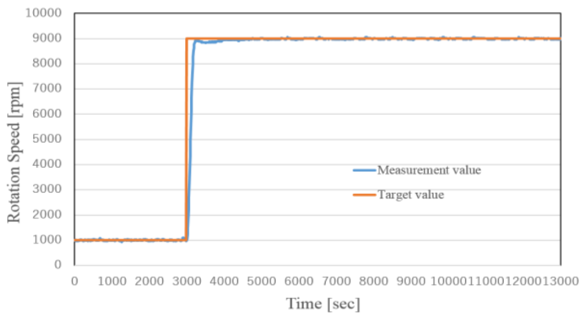


(a) 2000 rpm



(b) 6000 rpm



(c) 9000 rpm

Fig. 6. Experimental results

B. Experiments of Speed Control

An experiment to confirm whether the current revolution speed converges to a target speed by using the PD controller. The methods and results are shown below.

a) Experimental Method: An experimental setup is shown in Fig. 5, where the setup consists of a tilt rotor system, a rotor fixture, a stabilized power supply, and a PC. The initial revolution speed is set to 1000 rpm. Then, the target revolution speed is increased. The experiment is conducted in three cases where the target speed is set to 2000 rpm, 6000 rpm, 9000 rpm. Moreover, the gains of the PD controller are defined as K_p=0.0014 and K_d=0.08. These values are determined in experimentally.

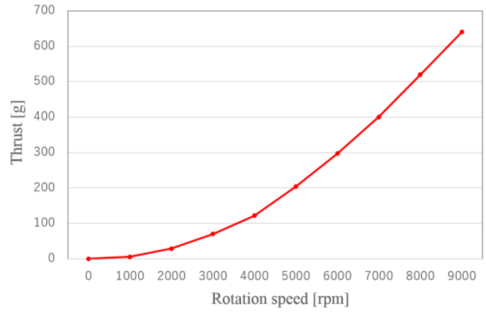


Fig. 7. Relationship between the revolution speed and the thrust

b) Experimental Results: Fig. 6(a) shows the measurement results for the case where the target speed is 2000 rpm. In this case, the current revolution speed converged to the target speed in approximately 0.2 seconds. Fig. 6(b) shows the measurement results for the case where the target speed is 6000 rpm. In this case, the current revolution speed converged to the target speed in approximately 1.5 seconds. Note, however, that slight overshoot occurred. There is a possibility that this overshoot may cause a bad influence in a flight. Fig. 6 (c) shows the measurement results for the case where the target speed is 9000 rpm. In this case, the current revolution speed converged to the target speed in approximately 1.5 seconds.

c) Consideration: It is found from these results that this PD controller can control the revolution speed of the rotor. However, gains of this PD controller should be adjusted to better values to eliminate the overshoot which occurred in the second case.

C. Measurement of Thrusts at Each Revolution Speed

To control the movement and attitude of rotary-wing type UAVs, it needs to measure the relationship between the revolution speed of the rotor and the thrusts generated by the rotor, in advance. An experiment is conducted to measure the relationship between the revolution speed and the thrusts generated by the rotor used in this research. The method and the results are shown below.

a) Experimental Method: An experimental setup adds an electronic scale to what was used in the previous experiment. The initial revolution speed of the rotor is set to 0 rpm. When increasing the revolution speed of the rotor every 1000 rpm, the thrusts generated by the rotor are recorded at each revolution speed. In addition, the maximum thrusts and revolution speed are also recorded.

b) Experimental Results and Consideration: Fig. 7 shows the experimental results. It is known that a thrust generated by a rotary-wing changes in proportion to the square of its revolution speed, assuming that an air density and a thrust coefficient are constant. These results show that the recorded thrusts are changed in proportion to the square of the

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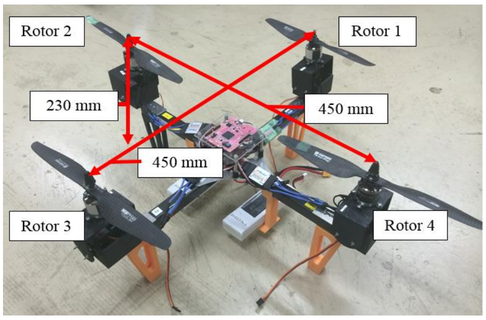

Fig. 8. Appearance of a new Quadrotor

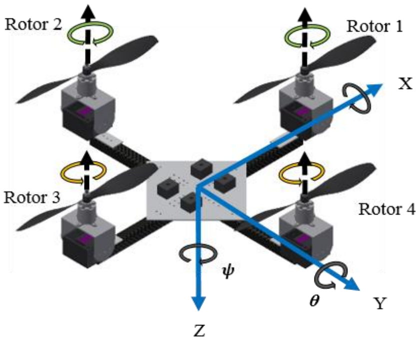

Fig. 9. Vertical flying mode

revolution speed. It is thought from this that the recorded thrusts are accurate. In addition, the recorded maximum thrust and revolution speed are 715 g and 9240 rpm. Then, maximum thrusts generated by using these four rotors are 2860 g. Generally, it is known that VTOL type UAVs need 1.3 times thrusts of their own weight to take off in vertical direction. Therefore, the weight limit of the Quadrotor with these four rotors is less than 2.2 kg.

IV. New Quadrotor

A. Appearance of the New Quadrotor

The appearance of the new Quadrotor is shown in Fig. 8. Four tilt rotor systems are attached to a conventional Quadrotor. It is 450 mm in length, 450 mm in width and 250 mm in depth, where it weighs approximately 1.8 kg. The rotors 1, 2 and 4 are operated among 0 deg to 90 deg. However, the propeller of the rotor 3 collides with the body of the Quadrotor, when the angle of rotor 3 is 45 deg. Then, the rotor 3 is operated among 0 deg to 30 deg for the safety.

B. Flying Modes

A vertical flying mode of the new Quadrotor is shown in Fig. 9. The angles of all rotors are 0 deg in this mode. Seeing from the upper part body, the rotational direction of the rotors 1 and 2 is clockwise, and similarly the one of rotors 3 and 4 is counterclockwise. The counter torque generated at each rotor is canceled by adopting these rotational directions, i.e., they can

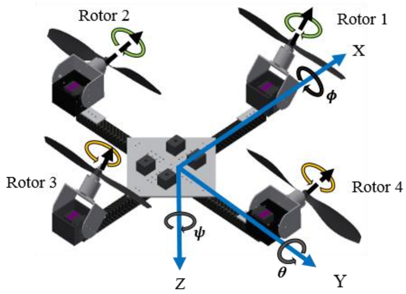

Fig. 10. Horizontal flying mode

prevent the body from being rotated around the ψ angle of the body. A horizontal flying mode of the new Quadrotor is shown in Fig. 10. The angles of the rotors 1 and 3 are 30 deg, whereas the tilt angles of the rotors 2 and 4 are 90 deg in this mode.

When the flying mode of the Quadrotor is changed from a vertical flying mode to a horizontal flying mode, only angles of the rotors 2 and 4 are changed first. After that, the angles of the rotors 1 and 3 are changed. This process can prevent the height of the Quadrotor from decreasing rapidly.

C. Future Works

When the Quadrotor changes its flying mode, it maintains its height by using vertical thrusts from the rotors 1 and 3. However, more vertical thrusts are needed in horizontal flying mode. Therefore, we are planning to attach a fixed wing, which can change its own angle like a tilt rotor system, to this Quadrotor.

V. Conclusion

This paper has described a tilt rotor system for a conventional Quadrotor. Next, a PD controller to control speed of the rotor was stated, and then, some experiments were conducted to check that the controller was effective. Finally, an outline of the new Quadrotor was also presented.

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