# A STUDY ON THE DYNAMIC MODELING FOR UNMANNED FLYING ROBOTS

**Ryu Cheol Bum[1], Yun Cheol[2] Email: Ryu1133@scientifictext.ru**

*[1]Ryu Cheol Bum - master of Engineering, Researcher;*
*[2]Yun Cheol - doctor of Engineering, Researcher,*
*DEPARTMENT OF CONTROL, FACULTY OF ELECTRONIC SCIENCE,*
*UNIVERSITY OF SCIENCE, PYONGYANG CITY, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA*

***Abstract:*** *quadrotor, which is most widely used and used among unmanned aerial vehicles, has recently been actively used for disaster and environmental monitoring, and its' performance and applications have been diversified and refined by the development of computer technology. Particularly, miniaturized quad rotors are widely used in difficult or dangerous areas in complex terrain environments. In this paper, we derived equations for dynamic modeling of a quadrotor unmanned aerial vehicle, derived the relationship between force and moment acting on it, and verified the behavior of the quadrotor by simulation.*
***Keywords:*** *quadrotor, simulation, dynamic.*

# ИССЛЕДОВАНИЕ ПО ДИНАМИЧЕСКОМУ МОДЕЛИРОВАНИЮ БЕСПИЛОТНЫХ ЛЕТАЮЩИХ РОБОТОВ

**Рю Чхоль Бом[1], Юн Чхол[2]**

*[1]Рю Чхоль Бом - кандидат технических наук, научный сотрудник;*
*[2]Юн Чхол - доктор технических наук, научный сотрудник,*
*кафедра управления, факультет электронной науки,*
*Институт естественных наук,*
*г. Пхеньян, Корейская Народно-Демократическая Республика*

***Аннотация:*** *квадротрон, который наиболее широко используется среди беспилотных летательных аппаратов, в последнее время активно используется для мониторинга стихийных бедствий и окружающей среды, а его производительность и приложения были диверсифицированы и усовершенствованы благодаря развитию компьютерных технологий. В частности, миниатюрные квадроциклы широко используются в сложных и опасных зонах в сложных ландшафтных средах. В этой статье мы получили уравнения для динамического моделирования квадрутерного беспилотного летательного аппарата, вывели соотношение между силой и моментом, действующим на него, и проверили поведение квадротора путем моделирования.*
***Ключевые слова:*** *квадротрон, моделирование, динамический.*

*УДК 681.5.017*

## Introduction

Unmanned aerial vehicles can be divided into two types depending on the wing shape: fixed wing and rotor wing. Recently, a rotor-wing quadrotor unmanned aerial vehicle has been widely used for movie shooting, security surveillance, environmental data collection, and especially for difficult or repetitive exploration purposes. [1,2] In this study, various simulations have been carried out to verify the relationship between the force and moment induced for the flight motion and the performance of the controller. The contents of the lecture are composed as follows. First, the definition and kinematic coordinates of a quadrotor are described, kinematic and dynamical modeling of the quadrotor is performed, the driving principle is explained, and a simulation based on a controller designed and designed for the quadrotor is performed. In the last chapter, we conclude and summarize the progressed research.

## 2. Quad rotor dynamic modeling

As shown in Fig. 1, the quadrotor has four propellers perpendicular to each other on one plane [3, 4]. The pitch movement is performed by the speed difference between the propeller 1 and the propeller 3, the roll movement is performed by the speed difference between the propeller 2 and the propeller 4, and the total lift of the propellers 1, 2, 3. And performs yawing motion by anti-torque generated by the speed difference of thrusters 1, 3 and 2, 4.

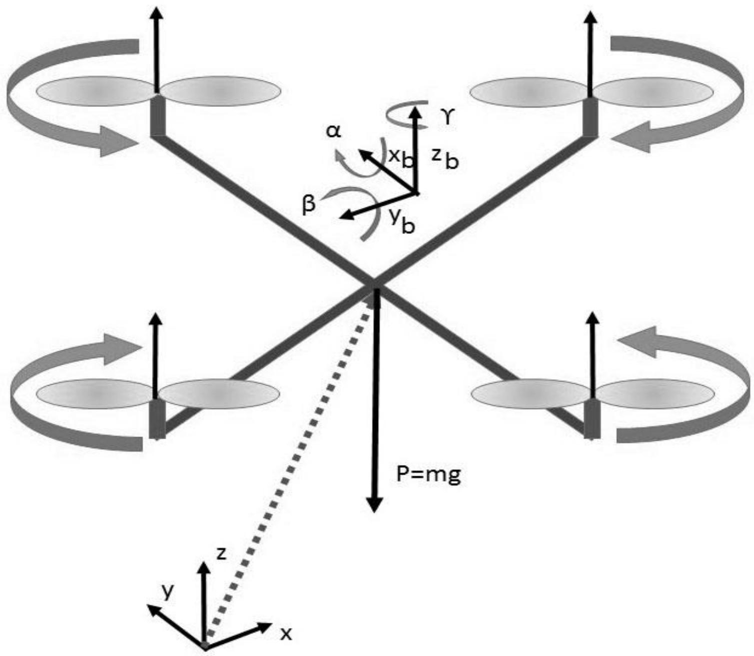


*Fig. 1. Coordinate system of the quadrotor*

All parts of the quad rotor are assumed to be rigid. Under this knowledge, the kinetic equation of a quad rotor can be derived as follows. As the coordinate system, inertial coordinate system fixed on the ground and body-fixed coordinate system are used. The position vector ($\boldsymbol{r}=[x\ y\ z]^{\mathrm{T}}$ ) and Euler angle ($\boldsymbol{e}=[\alpha\ \beta\ \Upsilon]^{T}$ ) of the quadrotor represented in the inertial coordinate system are related with the velocity (v=$[v_x, v_y, v_z]^T$ ) and the angular velocity (ω=$[\omega_x, \omega_y, \omega_z]^T$) of the moving body displayed in the body coordinate system.

$$\dot{\boldsymbol{r}} = \boldsymbol{T_r} \cdot \boldsymbol{v}$$
$$\boldsymbol{\omega} = \boldsymbol{T_\omega} \cdot \dot{\boldsymbol{e}} (1)$$

Where $\boldsymbol{T_r}$ and $\boldsymbol{T_\omega}$ are the rotation transformation matrix and the angular velocity transformation matrix between the fixed coordinate system and the body coordinate system, respectively, as follows.

$$\boldsymbol{T_r} = \boldsymbol{T_\alpha T_\beta T_\Upsilon} = \begin{bmatrix} cos\beta cos\gamma & sin\alpha sin\beta cos\gamma & cos\alpha sin\beta cos\gamma + sin\alpha sin\gamma \\ cos\beta sin\gamma & sin\alpha sin\beta sin\gamma & cos\alpha sin\beta sin\gamma - sin\alpha cos\gamma \\ -sin\beta & sin\alpha cos\beta & cos\alpha cos\beta \end{bmatrix} \qquad (2)$$

$$\boldsymbol{T_\omega} = \begin{bmatrix} 1 & 0 & -sin\beta \\ 0 & cos\alpha & sin\alpha cos\beta \\ 0 & -sin\alpha & cos\alpha cos\beta \end{bmatrix} \qquad (3)$$

Now, the following equation is obtained by differentiating the equation (1).

$$\ddot{\boldsymbol{r}} = \boldsymbol{T}_r \cdot \dot{\boldsymbol{v}} + \boldsymbol{T}_r \cdot \boldsymbol{\omega} \times \boldsymbol{v}$$

$$\dot{\boldsymbol{\omega}} = \boldsymbol{T_\omega} \cdot \ddot{e} + \dot{\boldsymbol{T}}_{\boldsymbol{\omega}} \cdot \dot{\boldsymbol{e}} \qquad (4)$$

From the definition of $\boldsymbol{T_\omega}$

$$\dot{\boldsymbol{T}}_{\boldsymbol{\omega}} = \begin{bmatrix} 0 & 0 & -\dot{\beta} cos\beta \\ 0 & -\dot{\alpha} sin\alpha & \dot{\alpha} cos\alpha cos\beta - \dot{\beta} sin\alpha sin\beta \\ 0 & -\dot{\alpha} cos\alpha & -\dot{\alpha} sin\alpha cos\beta - \dot{\beta} cos\alpha sin\beta \end{bmatrix} (5)$$

On the other hand, according to Newton's second law

$$m\dot{\boldsymbol{v}} + m\boldsymbol{\omega} \times (\boldsymbol{v}) = \boldsymbol{F} + m\boldsymbol{g} \qquad (6)$$

Since the dynamical treatment of the quadrotor is shown in several documents, we have simulated the operation of the quadrotor based on this.

**3. Quadrotor simulation MATLAB Simulink was created and simulated as follows.**

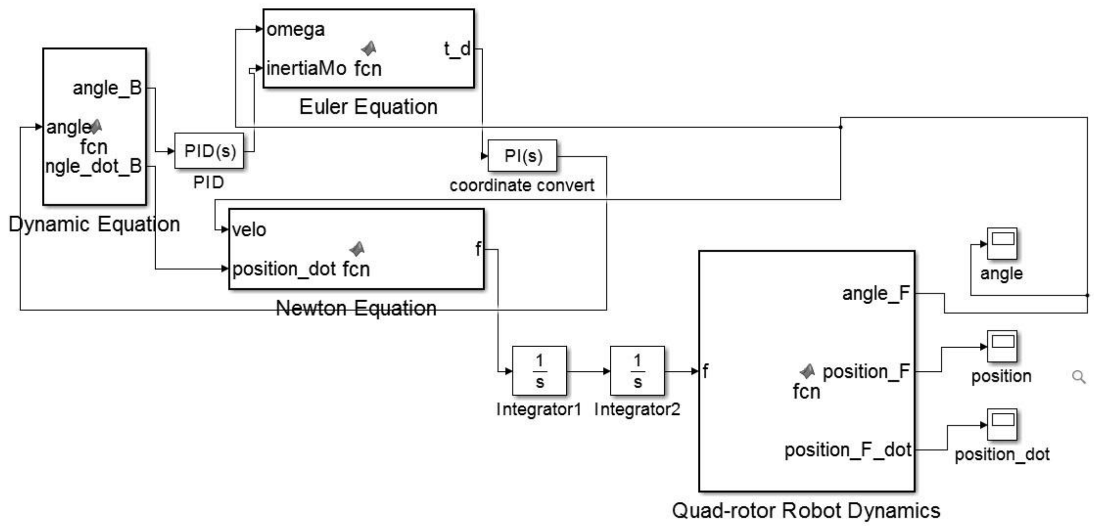


*Fig. 2. Quad rotor simulation*

The block diagram of the quad-copter simulator is shown in Fig. 2 and consists of kinetic equations, Newton's equations, Euler's equations, coordinate transformation, and Kalman filter. The simulation confirmed that the arrival time to the destination location and the arrival time to the direction angle were predicted. The following results are obtained when the target position x = 10, y = 20, z = 30 and the direction angle 2rad is set and simulated.

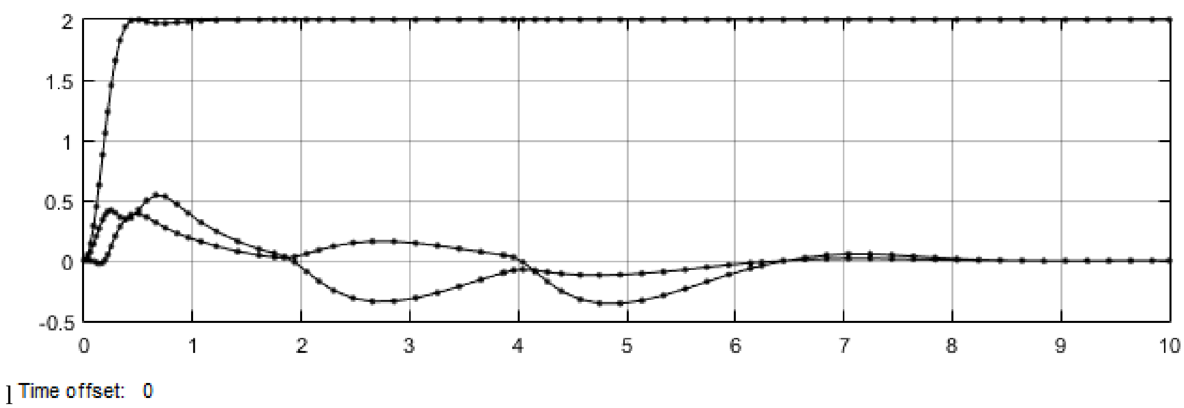


*Fig. 3. Directional simulation results*

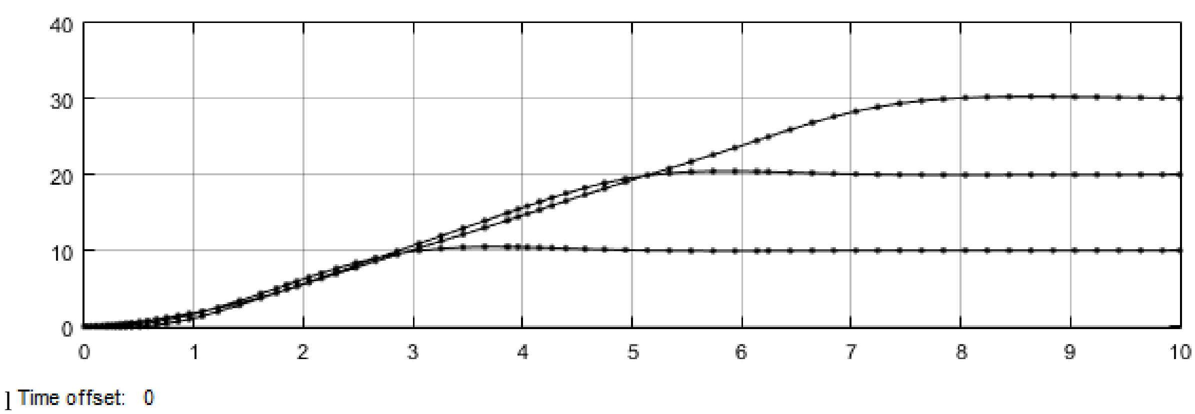


*Fig. 4. Location simulation result of aircraft*

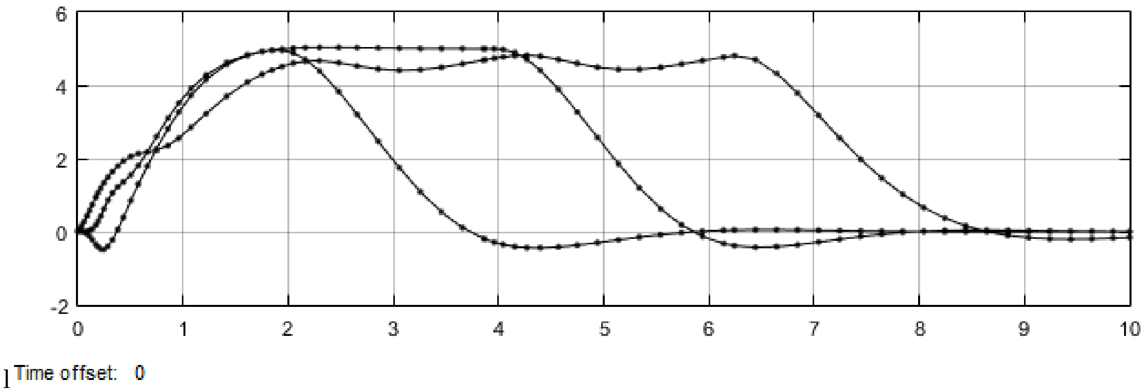


*Fig. 5. Aircraft speed simulation results*

As you can see, the direction angle converges to the target value 2rad within about 1s and the position reaches the target value in about 3 ~ 5s.

**4. Conclusion**

The purpose of this study is to establish the dynamical model of quad - copter and to implement the attitude, velocity, and direction angle estimation filters. Based on MATLAB Simulink, a simulator including a dynamical model, a posture estimation algorithm and a posture controller of a quadruple copter was constructed. We proposed a complementary filter and an extended Kalman filter based on the improved dynamic model when the attitude command was input through simulation.

### *References*

1. *Lee D.J., Kaminer I., Dobrokhodov V. and Jones K.,* 2010. “Autonomous Feature Following for Visual Surveillance Using a Small Unmanned Aerial Vehicle with Gimbaled Camera System”, International Journal of Control, Automation and Systems. Vol. 8. № 5. Pp. 957 - 966.
2. *Lee D.J. and Andersson, K.,* 2011. “Hybrid Control of Long-Endurance Aerial Robotic Vehicles for Wireless Sensor Networks,” International Journal of Advanced Robotic Systems, Vol. 8. № 2. Pp. 1 - 13.
3. *Das A., Subbarao K., Lewis F.* “Dynamic Inversion with zero-dynamics Stabilization for Quadrotor Control”, IET Control Theory and Applications, Vol. 3. № 3. Pp. 303 - 314, 2009.
4. *Hoffmann G., Huang H., Waslander S., Tomlin C.* “Quadrotor helicopter flight dynamics and control: theory and experiment”, Proceedings of the AIAA guidance, navigation & control conference, Hilton Head. SC. USA, 2007.