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Research Article

Investigation of the Effect of Differential Morphing on Lateral Flight by Using PID Algorithm in Quadrotors

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Abstract

Quadrotor is unmanned aerial vehicles that are widely used in military and civil fields. Quadrotors differ from conventional helicopters, which use rotors that are able to vary the pitch of their blades dynamically as they move around the rotor hub. Quadrotors generally use two pairs of identical fixed pitch propellers; two clockwise (CW) and two counterclockwise (CCW). These use independent variation of the speed of each rotor to achieve control. In this study, the quadrotor lateral flight and the effect of morphing on this flight were investigated. Morphing is called the change of unmanned aerial vehicles in their geometry. Newton-Euler method is used to create the quadrotor model. However, since the quadrotor is a system with non-linear dynamics, motion equations are converted to linear equations. The quadrotor full model was drawn in the Solidworks program, including batteries, controllers and propellers, in accordance with its actual dimensions. State space model approach was used in simulations in Matlab / Simulink environment. The value of mass and inertia moments from the Solidworks program is used in the state space model. Proportional integral derivative (PID) was used as the control algorithm. PID is an algorithm widely used in industrial applications. PID is preferred because it is strong, fast and simple. The system to which PID will be applied must be linear. The PID coefficients Kp, Ki and Kd are important for the stable operation of the system. Appropriate values should be chosen. In this study, lateral flight performance was monitored using differential morphing and PID algorithm and the results were presented.

Keywords: Quadrotor, Morphing, Control, PID, State Space Model.

1. Introduction

Quadrotors are unmanned aerial vehicles(UAV) that fall into the multirotor helicopter class. Quadrotors do not need any runway as they have vertical take off and landing feature. They are controlled by an autonomous or remote pilot. They do not carry cabin crew. Such unmanned aerial vehicles eliminate the risk of pilots' life. They are used in civilian areas for search and rescue, photography, cinema, hobby, agriculture, mapping and exploration. In the military field(Çoban & Oktay, 2018), they are used for many jobs such as coast, port, border security, military operations, surveillance.

In the past decade, quadrotor type unmanned aerial vehicles have had a major impact on aviation. Studies in this area have also gained importance in the literature. But most of the work is on modeling and control. In this study, the effects of differential morphing on lateral flight as well as modeling and control were investigated. The studies on morphing in the literature are as follows.

T. Oktay et al.(Oktay & Coban, 2017) developed a tactical unmanned aerial vehicle (TUAV) with both active and passive morphing structures. This vehicle weighed 50 kg, 3000 km range and could stay in the air for 28 hours. In their study, they determined the morphing rate by using SPSA, which is the optimization method. They used proportional integral derivative (PID) algorithm as both longitudinal and lateral flight controllers.

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T. Oktay and F. Sal(Oktay & Sal, 2016) used the active and passive morphing structure to save helicopter energy. Output Variance-Constrained Control (OVC) was used as the controller. They designed a powerful combined morphing system for model uncertainties.

T. Oktay et al.(Oktay et al., 2016) targeted payload UAV performance enhancement using active morphing. They used the PID algorithm as a controller. They designed an unmanned aerial vehicle combined with an active morphing structure carrying a total load of 6 kg.

T. Oktay and O. Kose(Oktay & Kose, 2019a, 2019b, 2019c) applied active morphing to an X-type quadrotor in their studies. In their study, they examined the effect of morphing on quadrotor hover longitudinal and lateral flights. They used PID as the control system. In simulations, they made the space space model in the presence of atmospheric turbulence. They observed that there was no effect in longitudinal flight when collective morphing, but morphing effect in lateral flight by observing design performance criteria.

In A. Desbiez(Desbiez et al., 2017) study, he made morphing of a quadrotor by changing the arm intersection angles. The arms could expand and contract right from the middle of the quadrotor via a motor. The goal was for the quadrotor to pass through narrow spaces. In his study, he showed that the quadrotor can sit in orbit and stabilize in the desired situation.

Y. Bai(Bai, 2017) designed a quadrotor that performs autonomous tasks with changes in geometry during flight. He did the morphing by changing the quadrotor arm intersection angles and by changing the arm lengths. In the simulation results, it showed that the control and stability were weakened in lateral flight.

2. Materials and Methods

2.1. Quadrotor Movements

A quadrotor consists of four rotors. As seen in Figure 1, the rotors are placed at the very end of the quadrotor arms. Each rotor generates a thrust while rotating. Take-off starts if the total thrust force of the four rotors exceeds the quadrotor weight. Quadrotor moves in x, y, and z axes. It also has 6 degrees of freedom (DOF). Quadrotor makes roll, pitch and yaw movements on axes. The difference from fixed wing unmanned aerial vehicles is that it has high maneuverability.

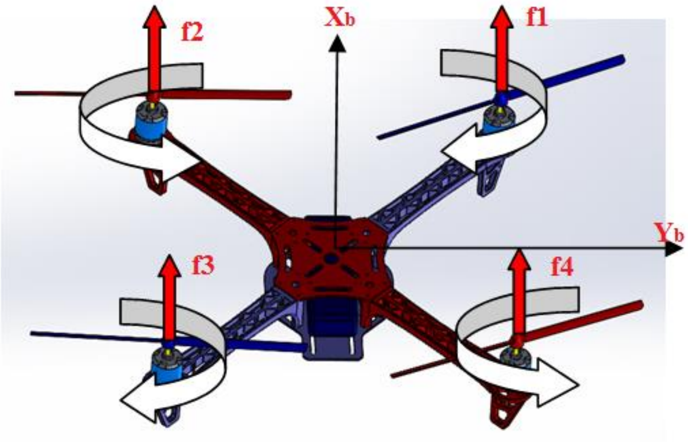

Figure 1: Quadrotor

The lateral movement covered in this study includes the roll movement. Quadrotor makes roll movement on X axis. As shown in Figure 2, if the quadrotor 2 and 3 motors increase their speed, and the motor speeds 1 and 4 decrease, the lateral movement will occur. Conversely, it performs lateral movement.

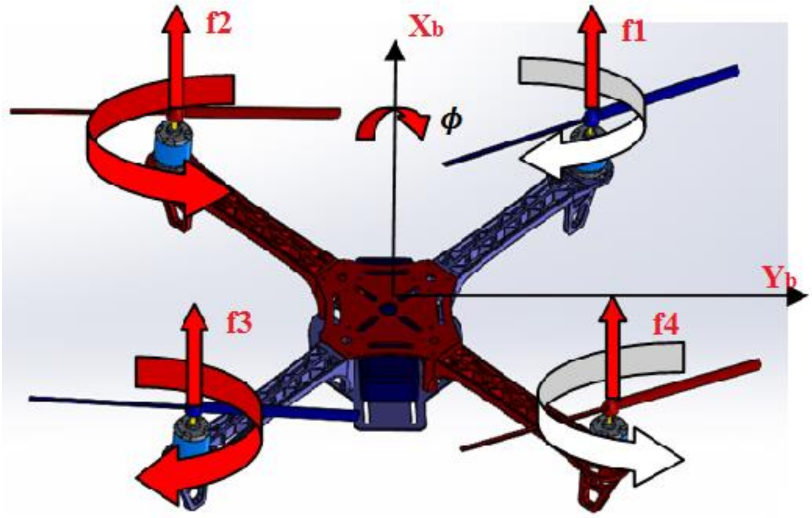

Figure 2: Roll motion

2.2. Dynamic Model

To realize the quadrotor movement, it needs Newton-Euler approach. The following views are accepted in this approach.

- The quadrotor structure is solid and symmetrical,
- The quadrotor propellers are solid,
- The quadrotor drift and propulsion are directly proportional to the square of speed,
- Ground effect is neglected.

Quadrotor is a system with non-linear dynamics. Although it is structurally simple, it has a complex structure as a mathematical model. Since the state space model approach is used in this study, non-linear motion equations are converted to linear equations with the help of various methods. The motion equations brought into linear state for lateral motion are as follows.

$$\begin{aligned} \dot{y} &= v \\ \dot{v} &= g\phi \\ \dot{r} &= \frac{\tau_z}{I_z} \\ \dot{p} &= \frac{\tau_x}{I_x} \\ \dot{\phi} &= p \\ \dot{\psi} &= r \end{aligned} \tag{1}$$

From these equations y, ϕ and quadcopter holds the linear and angular position and v, p and r hold the linear and angular velocities.

Express the Ix and Iz moments of inertia in motion equations. Moment of inertia is the diagonal matrix obtained from solid-body modeling(Domingue, 2009).

$$I = \begin{bmatrix} I_x & 0 & 0 \\ 0 & I_y & 0 \\ 0 & 0 & I_z \end{bmatrix} \tag{2}$$

In order to run Quadrotor motion equations, input to the equation system is required. For lateral movement, τ_x input is applied.

$$\tau_x = U_2 = bl(-\Omega_1^2 - \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \tag{3}$$

For lateral flight, U2 input is used. Where l the distance between any rotor and the center of the quadrotor, b is the thrust factor and d is the drag factor and Ω is propeller speed.

2.3. Differential Morphing and State Space Model

The process of changing the geometry of unmanned aerial vehicles in the air or on the ground is called morphing. Morphing is a new and developmental feature applied in unmanned aerial vehicles. In unmanned aerial vehicles, morphing is divided into two parts:

- Active morphing
- Passive morphing

If there is a change in geometry during the flight of the unmanned aerial vehicle, there is active morphing. But if changes are made to the geometry of the unmanned aerial vehicle on the ground before the flight, it is called passive morphing. It is realized by changing the arm angles or changing the arm lengths in quadrotor type unmanned aerial vehicles. Within the scope of this study, morphing will be done by changing the arm lengths. While Figrure 3 shows a normal length arm, Figure 4 shows the arm undergoing morphing.

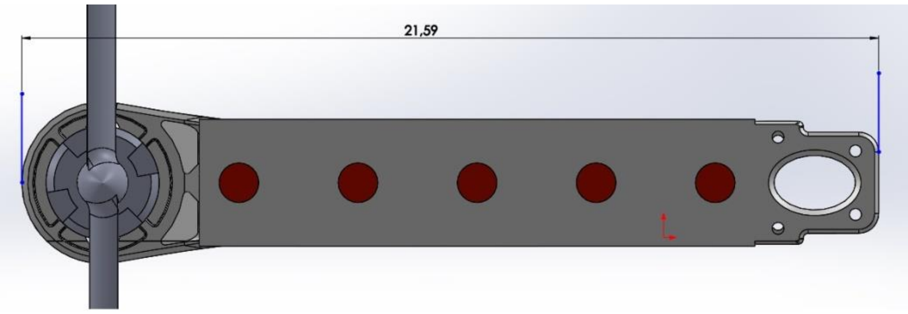

Figure 3: Normal arm

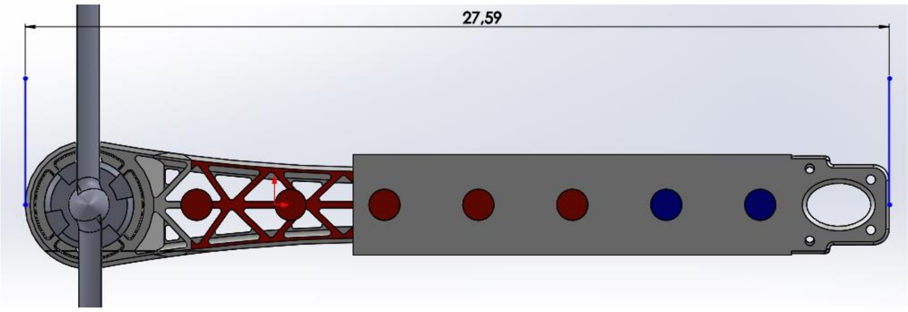

Figure 4: Morphing arm

State space model is an approach used in modeling of physical systems. The system is expressed in first order differential equations. By writing these equations in matrix form, the state space model is obtained. The general expression of the state space model is as follows.

$$\dot{x}=Ax(t)+Bu(t)$$

$$y=Cx(t)+Du(t)$$

Where,

x(t)= State vector, y(t)= Output vector, u(t)= Input or control vector, A= System matrix, B= Input matrix, C= Output matrix, D= Feedforward matrix.

In this study, lateral movement equations are shown in the state space model approach as follows.

$$\begin{bmatrix} \dot{y} \\ \dot{v} \\ \dot{p} \\ \dot{r} \\ \dot{\phi} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & g & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} y \\ v \\ p \\ r \\ \phi \\ \psi \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ {}^{1}/_{I_x} & 0 \\ 0 & {}^{1}/_{I_z} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \tau_x \\ \tau_z \end{bmatrix}$$

$$y = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} y \\ v \\ p \\ r \\ \phi \\ \psi \end{bmatrix}$$

2.4. Quadrotor Control System

PID algorithm was preferred in this study for quadrotor control. PID algorithm is preferred in many industrial applications due to its performance, strong structure and simplicity. The system where PID algorithm is applied must be linear. The general structure of PID is as follows.

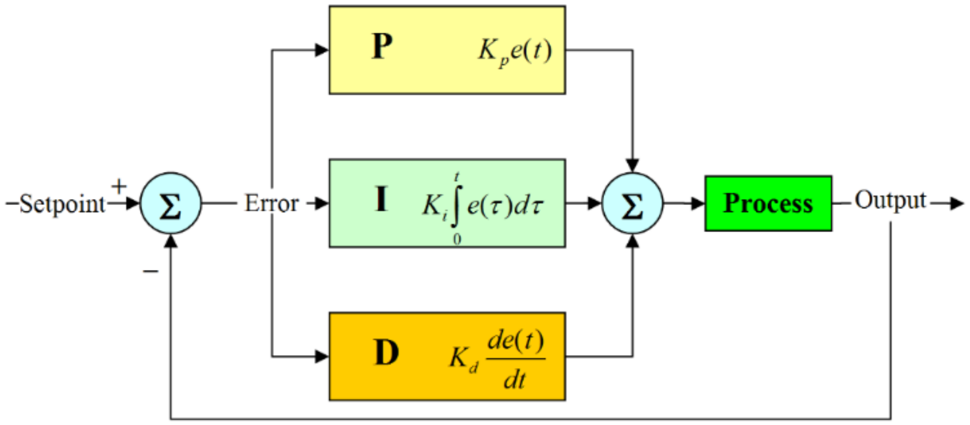

Figure 5: Structure of PID

The general formula of PID algorithm is given below.

$$u(t) = K_p\, e(t) + K_i\, \int_0^t (t)d(t)\, + K_d\, de(t)/d(t) \tag{4}$$

Where, K_p proportional gain, K_i integral gain and K_d is the derivative gain, e(t) the error caused by the difference between the reference and response of the system.

The performance of the PID algorithm depends on the proper selection of gain coefficients.

3. Results and Discussion

In this study, differential morphing was applied to the lateral flight. Differential morphing quadrotor is the length of the front and back arms of different lengths. Figure 6 shows a normal quadrotor, while Figures 7 and 8 show differential morphing states.

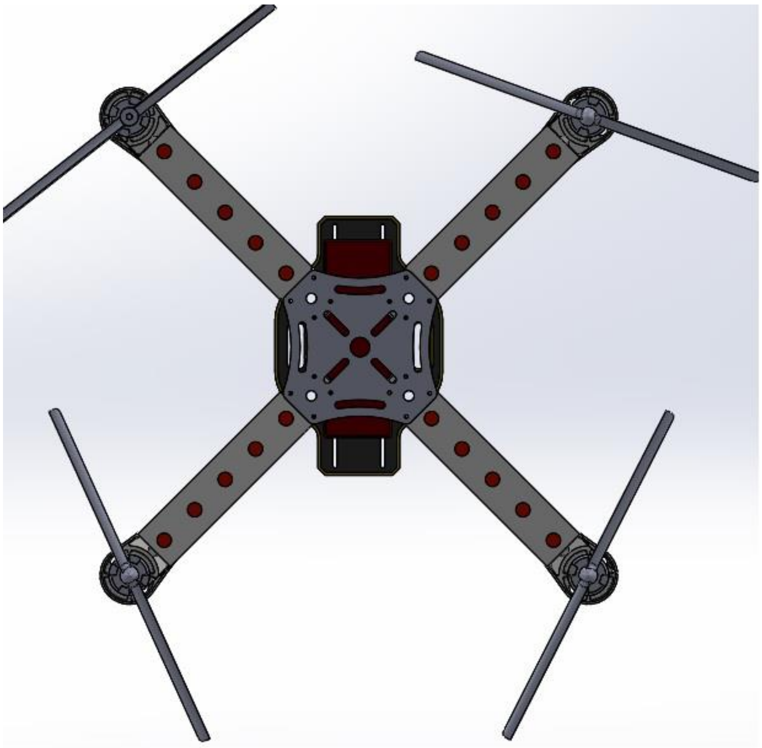

Figure 6: Normal arm length

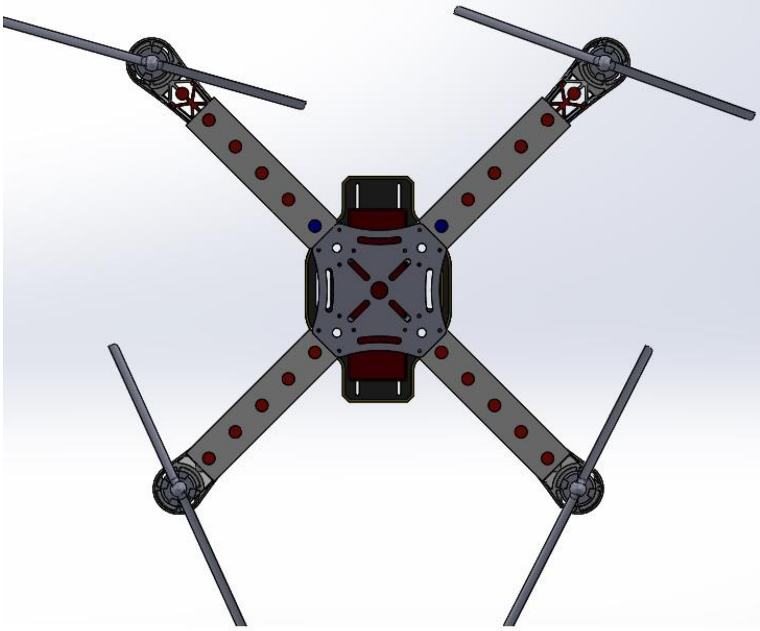

Figure 7: Differential morphing 1

Figure 8: Differential morphing 2

While the quadrotor performs morphing, $I_x$and I_z, which are moments of inertia, show variations, as the rigid body model changes. Since these values are in the space space model, they need to be updated with each morphing operation. In the table below, moment of inertia information is given.

Table 1: Quadrotor Moment of Inertia Values

State	$m(kg)$	$I_x(kg * m^2)$	$I_y(kg * m^2)$	$I_z(kg * m^2)$
Normal arm length	0.59	0.04085	0.01629	0.05607
Differential morphing 1	0.59	0.03859	0.00668	0.04418
Differential morphing 2	0.59	0.03982	0.00981	0.04856

PID coefficient values are always considered constant and are given in Table 2.

Table 2: Lateral Flight PID Coefficient

P	I	D
1.1	1.1	1.65

Lateral flight simulation graphics are given below.

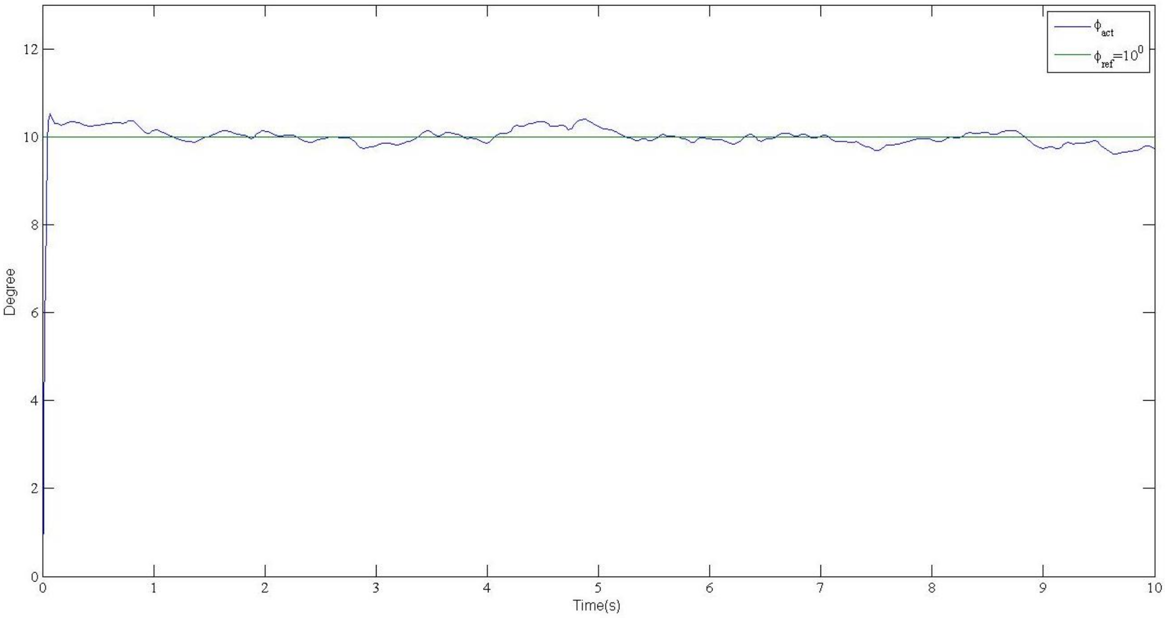

Figure 9: Normal arm simulation

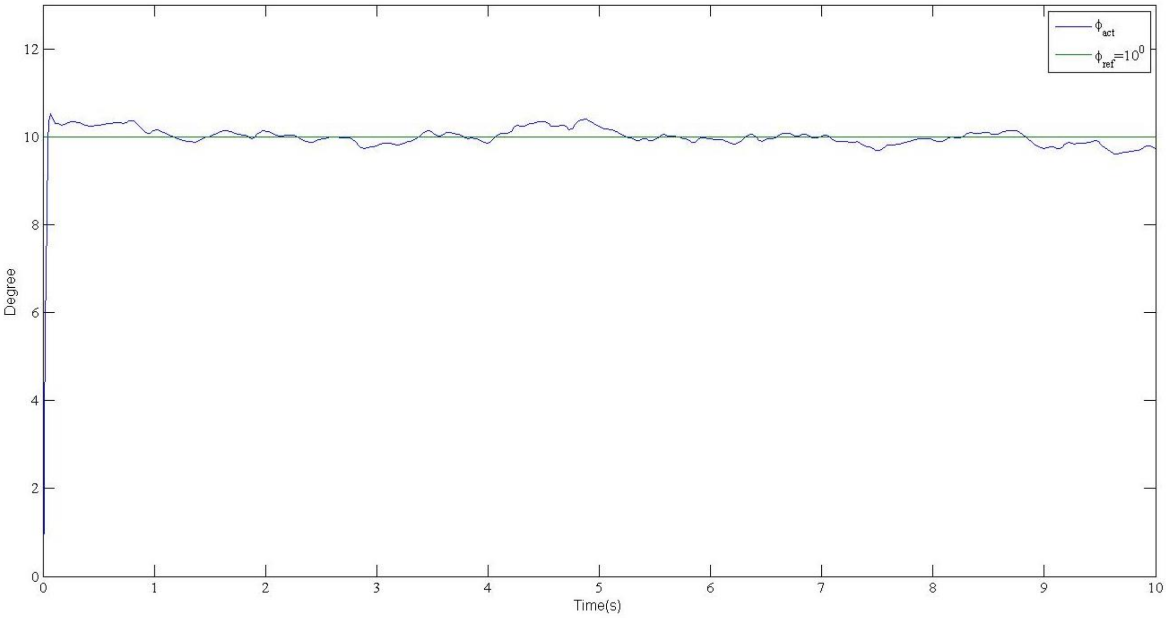

Figure 10: Differential morphing 1 simulation

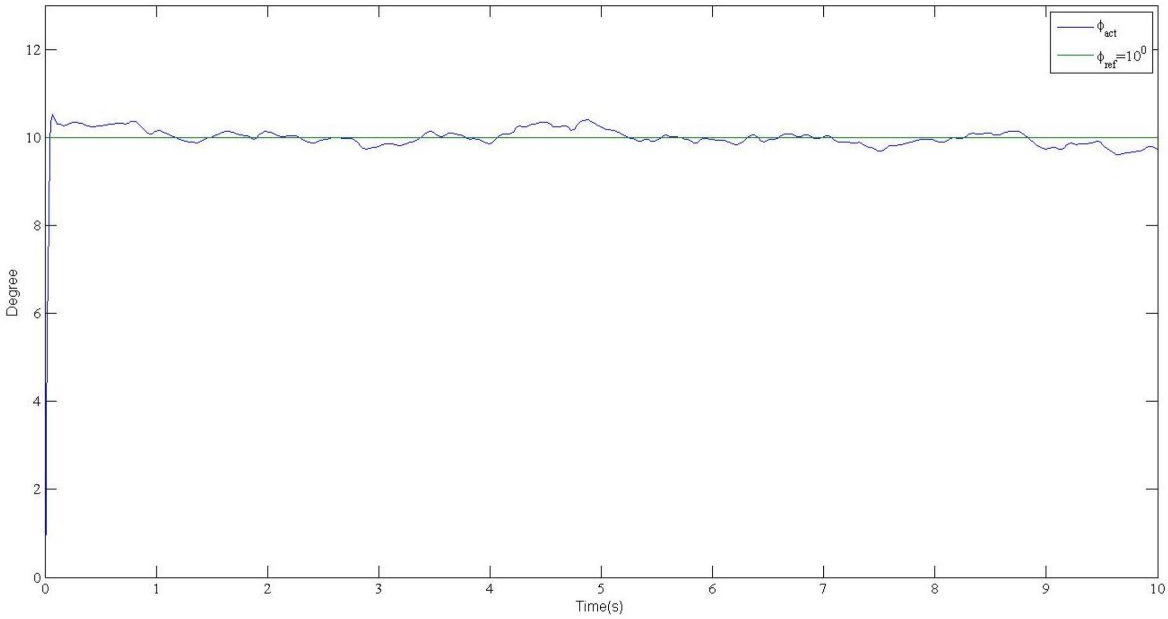

Figure 11: Differential morphing 2 simulation

4. Conclusions

In this article, the effect of differential morphing on lateral flight is discussed. The quadrotor dynamic model was created by the Newton-Euler method. The full model was drawn in the Solidworks program. With the mass and moment of inertia information taken from the full model, a model was created with the state space model approach in Matlab / Simulink environment and simulations were made.

Differential morphing was effective in lateral flight. Even if this situation is not clearly determined from the graphics, it was determined by observing the design performance criteria. Design performance graphs of non-morphing and morphing situations are given in the table below.

Table 3: Lateral Flight System Characteristic

	Non-morphing	Differential morphing 1	Differential morphing 2
Rise Time	0.0334 second	0.0316 second	0.0326 second
Settling Time	0.107 second	0.102 second	0.104 second
Overshoot	4.33 %	4.96 %	4.6 %

In this article, the PID coefficients remained constant in all cases. Morphing was done in certain proportions. In later studies, it is planned to determine PID coefficients according to morphing status and to provide more stable, stable flight by using optimization algorithms.

5. References

Bai, Y. (2017). *Control and Simulation of Morphing Quadcopter.* Saint Louis University,

Çoban, S., & Oktay, T. (2018). Legal and Ethical Issues of Unmanned Aerial Vehicles. *Journal of Aviation, 2*(1), 31-35.

Desbiez, A., Expert, F., Boyron, M., Diperi, J., Viollet, S., & Ruffier, F. (2017). *X-Morf: a crash-separable quadrotor that morfs its X-geometry in flight.* Paper presented at the 2017 Workshop on Research, Education and Development of Unmanned Aerial Systems (RED-UAS).

Domingue, J. M. (2009). *Quadrotor Prototype. Uneversidade Tecnica deLisboa.* Dissertacio,

Oktay, T., & Coban, S. (2017). Simultaneous longitudinal and lateral flight control systems design for both passive and active morphing TUAVs. *Elektronika ir Elektrotechnika, 23*(5), 15-20.

Oktay, T., Konar, M., Mohamed, M. A., Aydin, M., Sal, F., Onay, M., & Soylak, M. (2016). Autonomous flight performance improvement of load-carrying unmanned aerial vehicles by active morphing. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, 10*(1), 123-132.

Oktay, T., & Kose, O. (2019a). *The Effect of Collective Morphing on the Lateral Flight in Quadcopter*. Paper presented at the Umteb 6. Uluslararasi Mesleki ve Teknik Bilimler Kongresi, Iğdır.

Oktay, T., & Kose, O. (2019b). *The Effect of Collective Morphing on the Longitudinal Flight in Quadcopter*. Paper presented at the MAS INTERNATIONAL EUROPEAN CONGRESSON MATHEMATICS, ENGINEERING, NATURAL ANDMEDICAL SCIENCES-III, Şanlıurfa.

Oktay, T., & Kose, O. (2019c). *The Effect of Collective Morphing on the Vertical Flight in Quadcopter.* Paper presented at the MAS INTERNATIONAL EUROPEAN CONGRESSON MATHEMATICS, ENGINEERING, NATURAL ANDMEDICAL SCIENCES-III, Şanlıurfa.

Oktay, T., & Sal, F. (2016). Combined passive and active helicopter main rotor morphing for helicopter energy save. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 38*(6), 1511-1525.