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Lateral Control with Differential and Collective Morphing in Quadrotors

Oguz KÖSE[1]*, *Tuğrul OKTAY*[2]

[1] Gumushane University, Kelkit College of Aydın Dogan, Kelkit/Gumushane, Turkey
[2] Erciyes University, Department of Aeronautical Engineering, Kayseri, Turkey

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Abstract

Quadrotor are four-rotor unmanned aerial vehicles(UAV). These vehicles are widely used in military and civilian areas. They are preferred because they eliminate the risk of life of pilots. In this study, the effect of morphing, which is a new and developmental phenomenon in unmanned aerial vehicles, on lateral flight is discussed. Quadrotor modeling is achieved by Newton Euler approach. Models with quadrotor full and morphing states were drawn in Solidworks program. Simulations were made using the state space model approach in Matlab environment with the moment of inertia and mass values obtained in these models. Proportional integral derivative(PID) is used as the quadrotor control algorithm. Simulations are performed separately for each morphing situation. The results are presented with graphic and design performance criteria.

Keywords: Quadrotor, Morphing, Control, PID, UAV

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1. Introduction

Unmanned aerial vehicles (UAV) emerged as platforms popular in various applications such as rescue missions, fire fighting and reconnaissance. These vehicles can be used in hazardous environments as they are low cost and eliminate the risk of pilots' life. Quadrotors, a type of UAVs, have attracted the attention of researchers because they can take off and land vertically and are mechanically simple. Quadrotors don't need a runway as they can take off and land vertically. Therefore, they are more preferred than fixed wing UAVs. Many studies have been done on quadrotor modeling and control. However, studies on morphing, which constitute the main subject of this study, have started to take a new place in the literature. Some of these studies are listed below. In study in [1], Barbaracci discussed the modeling and control of a quadrotor with variable geometry. He tried to show how the angle between the arms affects longitudinal and lateral flight. He used LQR and proportional integral derivative (PID) algorithms as control algorithm. The simulations

Corresponding Author: Oguz Kose oguzkose24@gmail.com

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showed how different angles between the quadrotor arms affect the quadrotor flight. He worked on a foldable and quadrotor that can be used in works such as mapping and illustration in D. Falanga[2]. These Quadrotors could do H morphing, O morphing and T morphing because the arms could morphing from the joints to the body. The quadrotor was not symmetrical because it had different types of morphing features. Without this symmetry, the quadrotor provided a stable flight. V. Riviere et al. [3] worked on a quadrotor that can pass through narrow spaces.

The quadrotor had an elastic mechanism and could avoid obstacles. In the morphing process, there was a loss of control in the quadrotor roll axis in order to cope with this, the quadrotor developed a control system that kept it constant until a narrow area passed. T. Oktay and S. Coban [4] worked on the longitudinal and lateral flight control of the Tactical Unmanned Aerial Vehicle, which includes both passive and active morphing. This TUAV had a weight of 50 kg, a range of 3000 km, airborne time of 28 hours and a ceiling altitude of 12500 m. They calculated the optimum wingspan parameters using A stochastic optimization method named as simultaneous perturbation stochastic approximation (SPSA). They also calculated the controller coefficients with the same algorithm. T. Oktay and O. Kose [5]–[12] received the hover, longitudinal and lateral flights of the quadrotor with collective morphing. In their work, they worked on quadrotor modeling and control as well as morphing. They used PID as the control algorithm.

In this study, the effect of collective and differential morphing on lateral flight in an X-type quadrotor was investigated. In addition, quadrotor modeling and control are also discussed.

2. Material and Methods

2.1 Quadrotor Movements

Quadrotor is an unmanned aerial vehicle consisting of four rotors. It acts by taking advantage of the thrust produced by the rotors. Quadrotor performs its movement in the x, y and z axes. Quadrotor lateral movement is also called roll movement. The quadrotor performs its lateral movement on the X axis. Fig 1 shows the lateral movement.

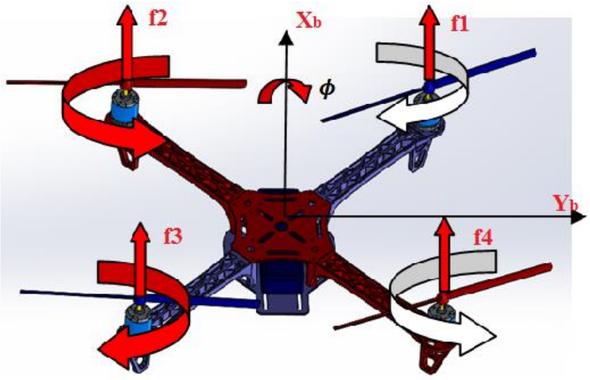

Figure 1. Lateral Movement

As shown in Figure 1, the rotors numbered 1 and 4 should decrease while the speed of rotors 2 and 3 should increase while the quadrotor would perform lateral movement.

2.2 Dynamic Model

Newton Euler method is used to obtain the quadrotor dynamic model [13], [14].

- The structure is solid and symmetrical.
- Propellers are solid.
- Ground effect is neglected.

Quadrotor is a nonlinear system. Although it is structurally simple, it is a complex system as a mathematical model. Nonlinear dynamics are converted into linear equations using various methods. Linear motion equations 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 ψ quadrotor holds the linear and angular position and v, p and r hold the linear and angular velocities.

I_x and I_x represent quadrotor moments of inertia[15].

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

In order to run quadrotor motion equations in simulations, an introduction to the system must be applied. τ_x is the entry for lateral actuation.

$$\tau_x = bl(-\Omega_1^2 - \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \qquad (3)$$

For lateral flight, τ_x 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 State Space Model and Morphing

State space model is a method used for modeling physical systems. In this method, physical system equations are expressed by first-order equations. These equations are modeled using the matrix form. The general form of the situation space model approach is shown below.

$$x = Ax(t) + Bu(t)$$
$$y = Cx(t) + Du(t)$$

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.

The lateral movement state space model discussed in this study is given below.

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

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

The process of changing the geometry of unmanned aerial vehicles is described as morphing. Morphing is carried out in two ways:

- Active morphing
- Passive morphing

If the unmanned aerial vehicle changes its geometry during flight, this is called active morphing. If the change in geometry is made on the ground before the flight, this is called passive morphing. In this study, active morphing was applied.

In the quadrotor type unmanned aerial vehicle, morphing occurs by lengthening and shortening the arm lengths.

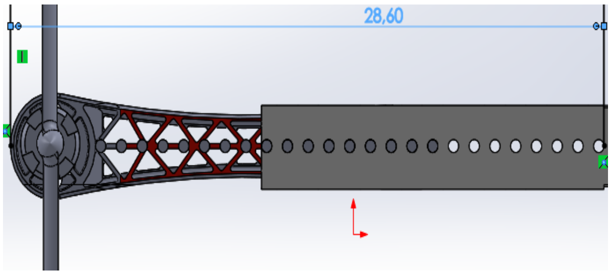

Figure 2. Normal arm

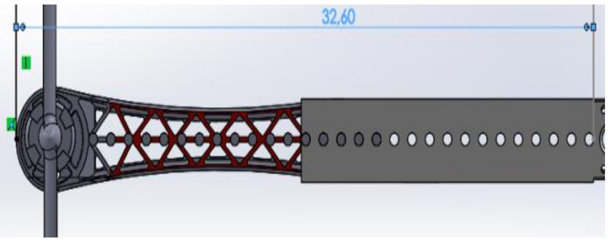

Figure 3. %50 morphing

2.4 Quadrotor Control System

PID algorithm was used in this study for quadrotor control. The PID controller is the most common form of feedback [16]. PID controllers are today found in all areas where control is used. PID controllers have survived many changes in technology, from mechanics and pneumatics to microprocessors via electronic tubes, transistors, integrated circuits. The general formula of PID algorithm is given below.

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

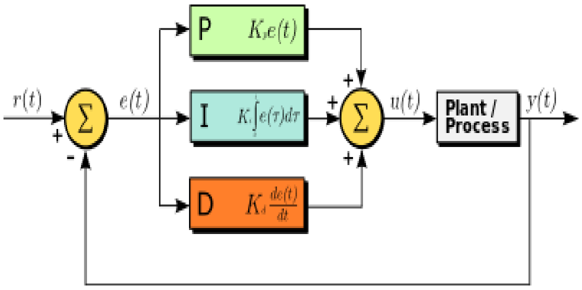

Figure 4. PID control

where y is the measured process variable, r the reference variable, u is the control signal and e is the control error. The reference variable is often called the set point. The control signal is thus a sum of three terms: the P-term (which is proportional to the error), the I-term (which is proportional to the integral of the error), and the D-term (which is proportional to the derivative of the error). The controller parameters are proportional gain K_p, integral gain K_i, and derivative gain K_d. The integral, proportional and derivative part can be interpreted as control actions based on the past, the present.

3. Result and Discussion

In this study, differential and collective morphing is discussed together. In differential morphing, the forearms are lengthened, while the back arms are shortened by the same amount. In collective morphing, the forearm and back arms are lengthened or shortened by the same amount. The differential and collective morphing states discussed for this study are shown below.

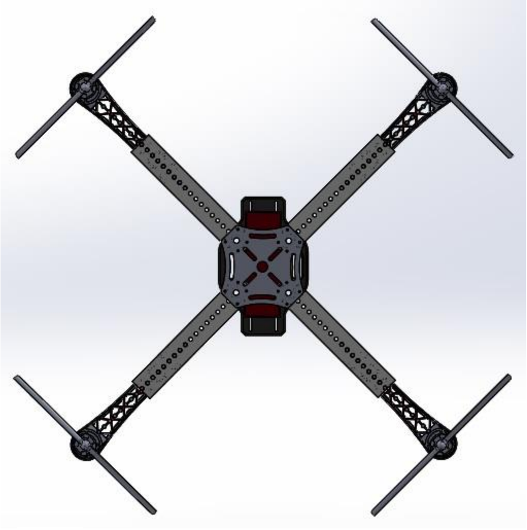

Figure 5. Initial situation

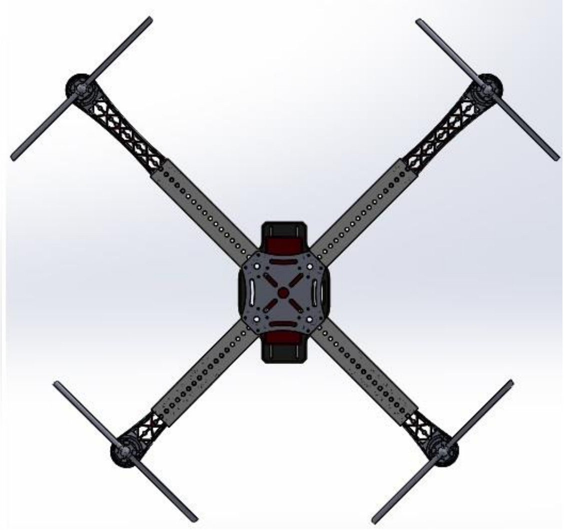

Figure 6. %50 differential and %50 collective morphing

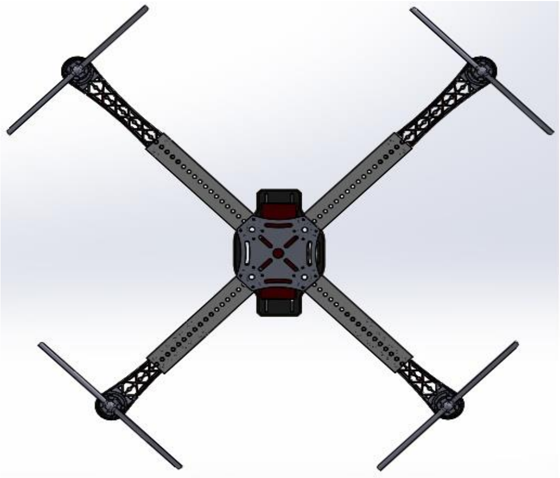

Figure 7. %50 differential and %25 collective morphing

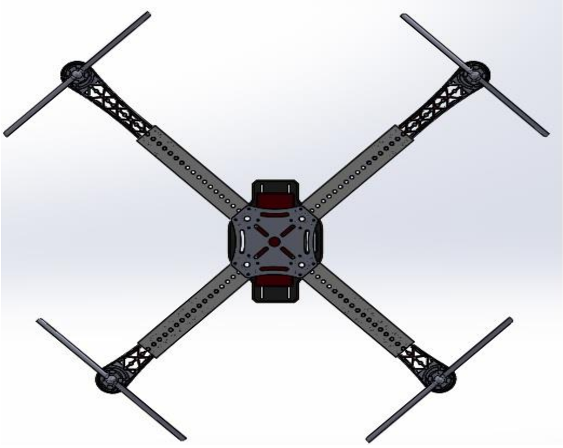

Figure 8. %25 differential and %50 collective morphing

There is no change in the quadrotor mass with differential and collective morphing. In the case of morphing, the quadrotor inertia moments change because the solid body model changes. Inertia moments are obtained from the models drawn in the Solidworks program. In the table below, inertia moments and mass information are given according to morphing states.

Table 1. Differential and Collective Morphing Moment of Inertia Change

	Fig 4	Fig 5	Fig 6	Fig 7
Ix(kg*m2)	0.03595	0.03596	0.03527	0.03659
Iy(kg*m2)	0.03543	0.03564	0.03490	0.03622
Iz(kg*m2)	0.02027	0.02049	0.01906	0.02170
m(kg)	0.60292	0.60292	0.60292	0.60292

PID coefficients remain the same in all cases of differential and collective morphing. PID coefficients are given in the table below.

Table 2. PID Coefficients

State	P	I	D
Differential and collective morphing	50	0.8	0.2

Simulation results in Matlab / Simulink environment are given below.

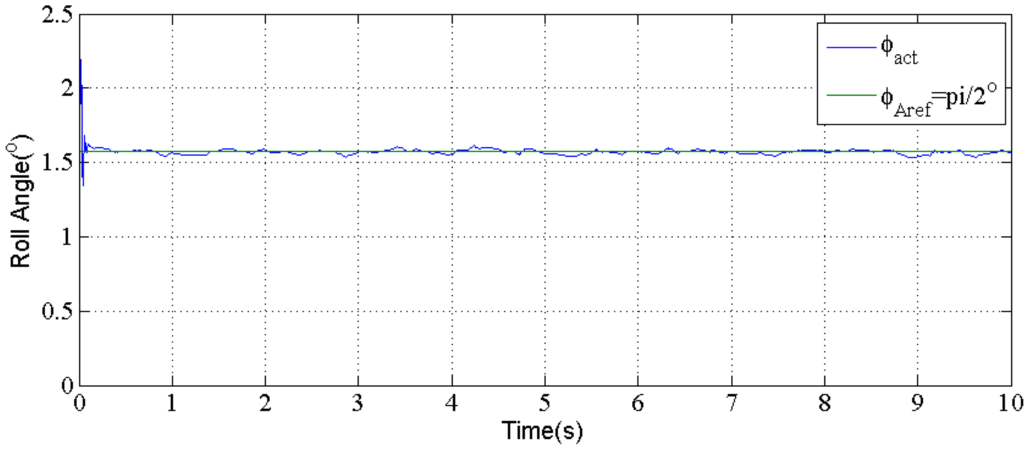

Figure 9. Initial situation simulation

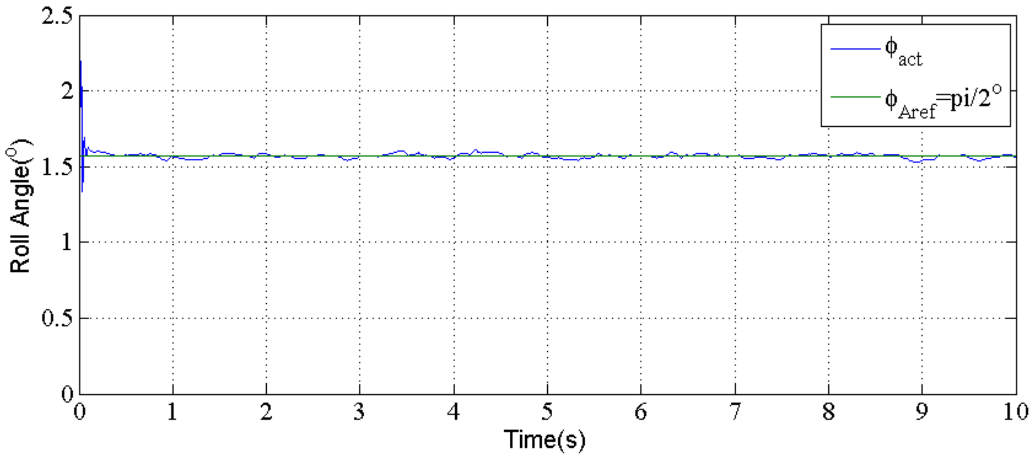

Figure 10. %50 differential and %50 collective morphing simulation

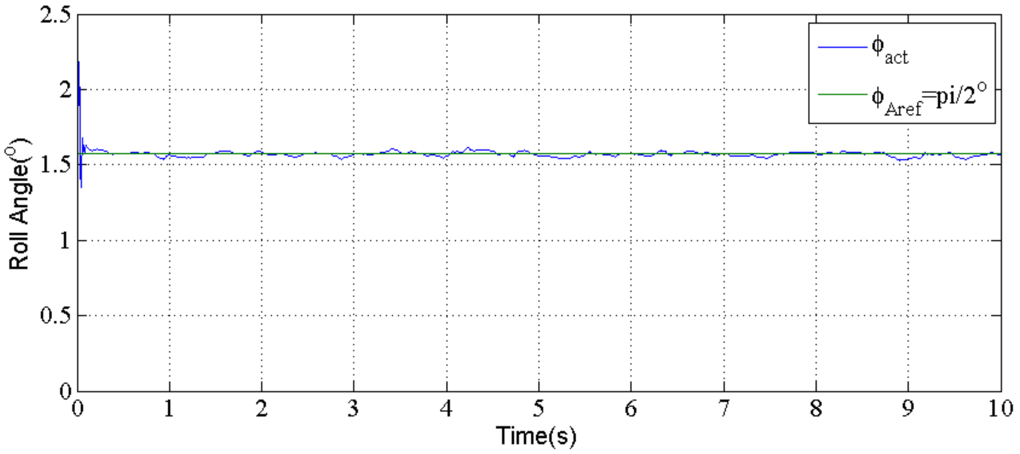

Figure 11. %50 differential and %25 collective morphing simulation

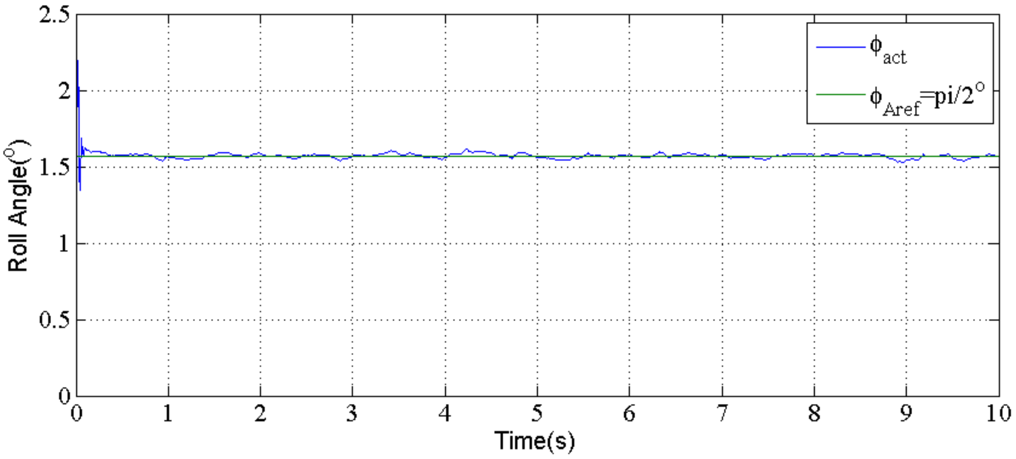

Figure 12. %25 differential and %50 collective morphing simulation

4. Conclusions

In this study, the effect of differential and collective morphing on the quadrotor lateral flight was investigated. Quadrotor created the dynamic model using the Newton Euler method. Quadrotor full model and every morphing situation were drawn in Solidworks program and mass and moment of inertia values were taken. Using these values, simulations were made using the state space model approach in Matlab environment.

According to simulation results, differential and collective morphing had an effect on lateral flight. The main reason for this is that the quadrotor inertia moments change in each morphing situation. These inertia moment values have an effect on flight since the state is applied as an input to the space model. Rise time, settling time and overshoot values, which are the design performance criteria that affect the lateral flight, can be seen by monitoring.

Table 3. Differential and Collective Morphing Design Performance Criteria

	Fig 4	Fig 5	Fig 6	Fig 7
Rise Time	0.00757 sec	0.00757 sec	0.0748 sec	0.00765 sec
Settling Time	0.0996 sec	0.0996 sec	0.0988 sec	0.1 sec
Overshoot	42.1 %	42.1 %	42.4 %	41.8 %

Ethical Approval

Not applicable.

References

[1] G. Barbaraci, “Modeling and control of a quadrotor with variable geometry arms,” *J. Unmanned Veh. Syst.*, vol. 3, no. 2, pp. 35–57, 2015.

[2] D. Falanga, E. Mueggler, M. Faessler, and D. Scaramuzza, “Aggressive quadrotor flight through narrow gaps with onboard sensing and computing using active vision,” *Proc. - IEEE Int. Conf. Robot. Autom.*, pp. 5774–5781, 2017, doi: 10.1109/ICRA.2017.7989679.

[3] V. Riviere, A. Manecy, S. Viollet, V. Riviere, A. Manecy, and S. Viollet, “Agile robotic fliers : a morphing based approach To cite this version : HAL Id : hal-01803737 Agile robotic fliers : a morphing based approach,” 2018.

[4] T. Oktay and S. Coban, “Simultaneous longitudinal and lateral flight control systems design for both passive and active morphing TUAVs,” *Elektron. ir Elektrotechnika*, vol. 23, no. 5, pp. 15–20, 2017, doi: 10.5755/j01.eie.23.5.19238.

[5] O. and Kose and T. Oktay, “Optimal Tunning of PID Controller For Forward Flight of Research Based Quadrotor,” *2. Uluslararası Multidisipliner Çalışmaları Kongresi*. Adana, 2018.

[6] O. and Kose and T. Oktay, “Dynamic Modeling and Simulation of Quadrotor for Different Flight Conditions,” *Eur. J. Sci. Technol.*, vol. 15, pp. 132–142, 2019.

[7] O. Kose and T. Oktay, “Non Simultaneous Morphing System Desing for Quadrotors,” no. 16, pp. 577–588, 2019, doi: 10.31590/ejosat.569785.

[8] T. Oktay and O. Kose, “The Effect of Collective Morphing on the Longitudinal Flight in Quadcopter,” *Mas International European Congresson Mathematics, Engineering, Natural Andmedical Sciences-III*. Şanlıurfa, 2019.

[9] T. Oktay and O. Kose, “The Effect of Collective Morphing on the Lateral Flight in Quadcopter,” *Umteb6. UluslararasiMesleki ve Teknik Bilimler Kongresi*. Iğdır, 2019.

[10] T. Oktay and O. Kose, “Survey on Morphing Methods for Quadcopter,” *Umteb6. UluslararasiMesleki Ve Teknik Bilimler Kongresi*. Iğdır, 2019.

[11] T. Oktay and O. Kose, “The Effect of Collective Morphing on the Vertical Flight in Quadcopter,” in *Mas International European Congresson Mathematics, Engineering, Natural Andmedical Sciences-III*, 2019, pp. 1–10.

[12] T. Oktay and O. Kose, “Non Simultaneous Morphing System Design for Yaw Motion in Quadrotors,” *J. Aviat.*, vol. 3, no. 2, pp. 81–88, 2019.

[13] A. Marks, J. F. Whidborne, and I. Yamamoto, “Control allocation for fault tolerant control of a VTOL octorotor,” *Proc. 2012 UKACC Int. Conf. Control. Control 2012*, no. September, pp. 357–362, 2012, doi: 10.1109/CONTROL.2012.6334656.

[14] S. Bouabdallah, “Design and control of quadrotors with application to autonomous flying,” Epfl, 2007.

[15] J. Domingues, “Quadrotor prototype,” *Inst. Super. Tec. Univ. Tec. ...*, no. October, p. 129, 2009, [Online]. Available: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Quadrotor+prototype#4.

[16] K. J. Åström and T. Hägglund, *Control PID avanzado*. Pearson, Madrid, 2009.