

**Research Article****Modelling and Control of Proposed Two Dodecacopter Systems****Şahin Yıldırım^{a,*} , Nihat Çabuk^b , Veli Bakırcıoğlu^b** ^a*Mechatronic Engineering Department, Faculty of Engineering, Erciyes University, Kayseri, Turkey*^b*Aksaray University, Technical science Vocational school, Aksaray, Turkey*

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ABSTRACT

Nowadays, the use of multi-propellers has been increased, because of some basic advantages such as vertical take-off and landing, simple mechanical structure. In addition, different usage fields such as carrying an object and making video records over the cities. This paper exposes design and control of two different multi propeller systems and both systems have 12 rotors to carry more load. In first, all motors are arranged at identical angles in the same plane. In the other, the motors are mounted in two groups, eight and four in two different planes, the lower and upper. Flight performances of these two different UAVs were compared under disturbing effect. It was observed that the flight performances were close in the simulation study. Although the average and maximum of the position errors for three axes in the first model was less than the other, for the same propeller dimensions, the first model must have larger dimensions than the other in the context of the smallest vehicle dimensions.

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1. Introduction

Unmanned Aerial Vehicles (UAVs) have recently aroused great interests in both industrial and military fields. UAV is a type of very complex system which integrates different hardware components, such as camera, Global Positioning System (GPS), Inertial Management Unit (IMU), controller, and different software components, such as image processing, path planning and inner loop control [1]. Due to the ability to perform dangerous and repetitive tasks in remote and hazardous environments, UAV is very promising to play more important roles in many applications and recent developments have proven the benefits in different ways [2].

Multirotor UAVs are capable of take-off and landing vertically (VTOL). Six degree-of-freedom are obtained by changing the angular speed of the motors of these vehicles. The number of motor variable from three and eight standards on the basis of these according to the usage of the vehicle are determined.

Brushless DC motors [3] are mostly used in these vehicles. These motors derive their energy from lithium

polymer (Li-PO) batteries [4]. The energy requirement of the vehicle in consideration when determining the total weight of the vehicle, the weight of the vehicle motor and also the selection of the proper propeller is one of the important issues in the design. Regardless of the weight of the vehicle, a controller card and software which will be used to control the vehicle in the desired manner requires sensors that help to fly of the vehicle.

To measure roll, pitch and yaw positions, velocities and accelerations is used a gyro sensor, to measure height of the vehicle is used a pressure sensor, to determine of direction of the vehicle is used compass, to measure the global position of the vehicle is used a GPS. Especially the GPS and compass sensors are able to basically be affected by the magnetic field of the vehicle in the calibration and use of the vehicle because this point in time are taken into consideration. Used to drive motors, each motor suitable for electronic speed controller (ESC) is one of the important components of. The motors which supply power to the ESC and wires and connection cables since it may be exposed to high temperatures that will be used should be selected in consideration of this point solders.

Mechanically the vehicle is designed to consider the

total weight of the vehicle when one of the important issues. In the mechanical structure, the main consideration is durability and lightness. For this reason, the material to be used should be chosen accordingly. The physical design and control of multirotor air vehicle have studied in the literature [5-16]. Taehyung Kim, and sung-Kyung Hong [2], multicopter hybrid design study, two internal combustion engine the center of gravity multicopter, brushless DC motors have developed through the four corners of a four-Assembly model. As a result of the application of this model expressed that they get more flight time.

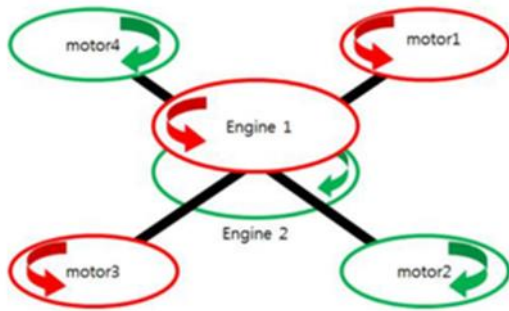


Figure 1. Hybrid multi propeller model [2]

China E. Lin et al. [17], developed a hybrid vehicle model by installing four short-arm internal combustion engines and four long-arm dc motors. Longer flight times and greater load capacity are made to enable the goals of this study stated that they have achieved.

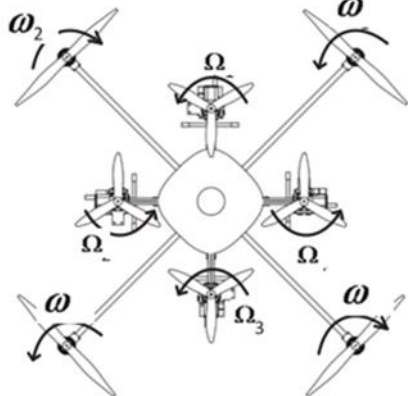


Figure 2. Other type multi propeller model [17]

J. Verbeke et al. [1], said that we have conceived a novel compound multicopter configuration specifically for flight through narrow corridors, its design combines the contradictory requirements of limited width, high agility and long endurance while carrying a significant payload.

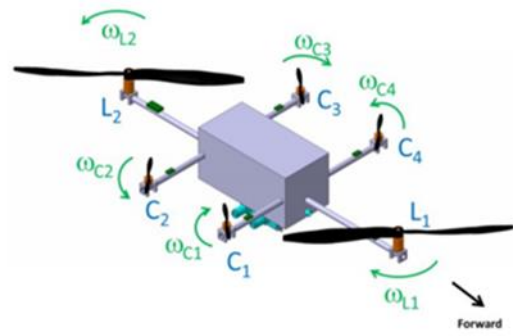


Figure 3. Model of multicopter with different wind [1]

In this study, two different types of dodecicopter models which are non-traditional structure were developed and simulated for the purpose of carrying loads. The general mathematical model of multi-rotor UAVs can be examined from our previous study [18], as in many publications [19, 20].

2. Design and modelling

Multi propeller systems begin to design various mechanical systems required for electrical, electronic and mechanical components of the supply phase. These design updates will be made according to changes which may occur in mechanical components. SolidWorks is used to mechanical design and MATLAB program is used to analysis as a simulation program.

In this study, for high lifting capacity, two different types of multicopter air vehicle models with 12 rotors have been proposed. The motors in these models was selected as one of the reasons why the high number of a motor or drive the vehicle in the event of some malfunction of the balance of the ability to make easy and to ensure a safe landing. In this situation it is necessary to develop a suitable control algorithm.

In the first model as seen fig. 4, 12 motors which are independently controlled are arranged at identical angles in the same plane.

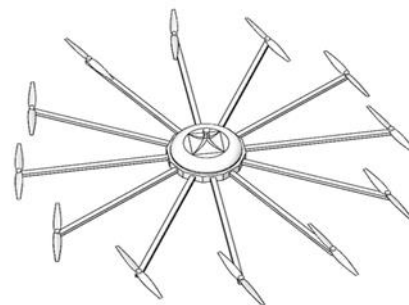


Figure 4. Proposed 12 dodecicopter model

In the second model, smaller sizes to achieve higher lifting capacity is eight in the upper plane of the motors while the four motors are placed on the lower plane and 8+4 dodecicopter model was created as seen in fig. 5.

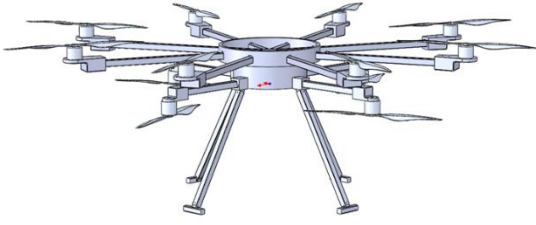


Figure 5. Proposed 8+4 dodecacopter model

The motors are mounted on the vehicle, which is planned to be used for motor and propeller, which will occur according to the thrust values for the example are given in Table 1 below. This table KDE4215XF KDE Direct motor with a value of 465 Kv which is planned to be used in this study model of a DC motor belongs to.

Table 1. A proposed motor and propeller thrust values

Throttle Range [%]	Current [A]	Power [W]	Velocity [RPM]	Thrust [g]
25	2.4	62	3360	620
50	8.5	221	5340	1670
75	23.2	605	7500	3340
100	45.2	1179	9300	5360

According to this table, the most relevant in the period 15.5-inch motor with a propeller of high thrust 5360 g value in the scale value can be obtained. The weight of the vehicle, which is one of the most important parameters in the selection of take-off have a direct effect on the motor and propeller should be considered. Each of the propeller and the brushless DC motor manufacturers are served by the appropriate table according to. The maximum approximate thrust value for both vehicle models is 64 kg according to table 1.

The mathematical model was obtained for the dodecacopter system. Relationship between angular velocities of the motors and the body forces can be formed by a matrix C as in Eq. (1), and angular velocities of the dodecacopter system defined by a vector Ω in Eq. (2). The desired thrust forces and the moments are indicated by the U_d vector.

$$U_d = C * \Omega^2 \tag{1}$$

$$\Omega^2 = [\Omega_1^2 \ \Omega_2^2 \ \Omega_3^2 \ \Omega_4^2 \ \Omega_5^2 \ \Omega_6^2 \ \Omega_7^2 \ \Omega_8^2 \ \Omega_9^2 \ \Omega_{10}^2 \ \Omega_{11}^2 \ \Omega_{12}^2]^T \tag{2}$$

The vector U_d is given as Eq. (3), which includes the needed forces and moments for the motion.

$$U_d = \begin{bmatrix} F_t \\ M_r \\ M_p \\ M_y \end{bmatrix} \tag{3}$$

The matrix C_1 which is for first model is constant and it can be calculated according to the first vehicle's configuration as in Eq. (4).

$$C_1 = \begin{bmatrix} k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} & k_{f1} \\ \beta & \gamma & \lambda & \lambda & \gamma & \beta & -\beta & -\gamma & -\lambda & -\lambda & -\gamma & -\beta \\ \lambda & \gamma & \beta & -\beta & -\gamma & -\lambda & -\lambda & -\gamma & -\beta & \beta & \gamma & \lambda \\ k_{m1} & k_{m1} & -k_{m1} & -k_{m1} & -k_{m1} & -k_{m1} & k_{m1} & k_{m1} & -k_{m1} & -k_{m1} & k_{m1} & k_{m1} \end{bmatrix} \tag{4}$$

The matrix C_2 which is for second model is constant and it can be calculated according to the vehicle's configuration as in Eq. (5).

$$C_2 = \begin{bmatrix} k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} & k_{f2} \\ \Lambda & -\Lambda & \Delta & \Lambda & -\Lambda & -\Delta & -\Delta & \Delta & \Gamma & -\Gamma & -\Gamma & \Gamma \\ \Delta & -\Delta & \Lambda & -\Lambda & -\Delta & \Delta & \Lambda & -\Lambda & \Gamma & -\Gamma & -\Gamma & \Gamma \\ k_{m2} & k_{m2} & -k_{m2} & -k_{m2} & -k_{m2} & -k_{m2} & k_{m2} & k_{m2} & -k_{m2} & -k_{m2} & k_{m2} & k_{m2} \end{bmatrix} \tag{5}$$

For the sake of simplicity of the matrixes, β , γ , Λ , Δ and Γ given in Eq. (6)

$$\begin{aligned} \beta &= k_{f1} * l_1 * \sin(15) \\ \gamma &= k_{f1} * l_1 * \sin(45) \\ \lambda &= k_{f1} * l_1 * \sin(75) \\ \Lambda &= k_{f2} * l_u * \sin(22.5) \\ \Delta &= k_{f2} * l_u * \sin(67.5) \\ \Gamma &= k_{f2} * l_d * \sin(45) \end{aligned} \tag{6}$$

where, k_{f1} and k_{f2} are thrust factors, k_{m1} and k_{m2} reverse moment factors for first and second model, respectively. These factors are obtained experimentally. Besides, l_u and l_d arm length in upper plane and lower plane of second model, respectively. Then, l_1 is arm length for first model. The F_t is the desired force that acts on the body and M_r and M_p are desired roll and pitch moments. M_y is yaw moment, which is the sum of the reaction moments caused by each rotor with propeller.

3. Simulation Studies

Simulations were carried out with the prescribed trajectory of the proposed both multi propeller models design.

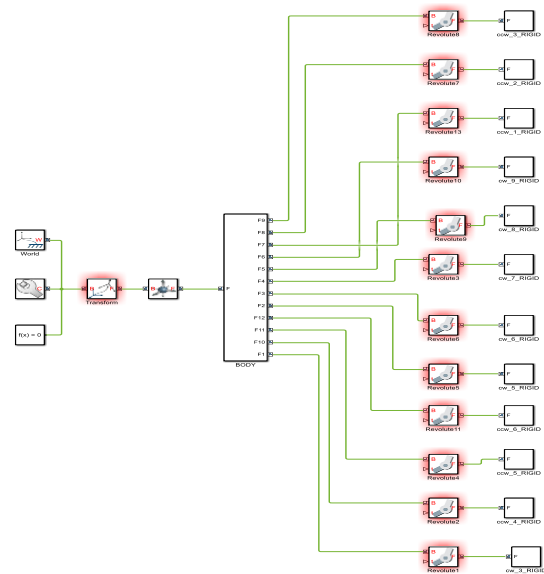


Figure 6. Simulink model of the multi-propeller air vehicles

As shown in figure 6, the Simulink model is obtained to simulate by transferring the 3-D models of the vehicles obtained by a CAD program to MATLAB with their all physical parameters.

Trajectory of the proposed system was controlled by using standard PID controller with constant gain parameters. However, gain parameters of the controller were tuned with empirically. The systems were modelled and controlled by MATLAB Simulink model as seen in Figure 7.

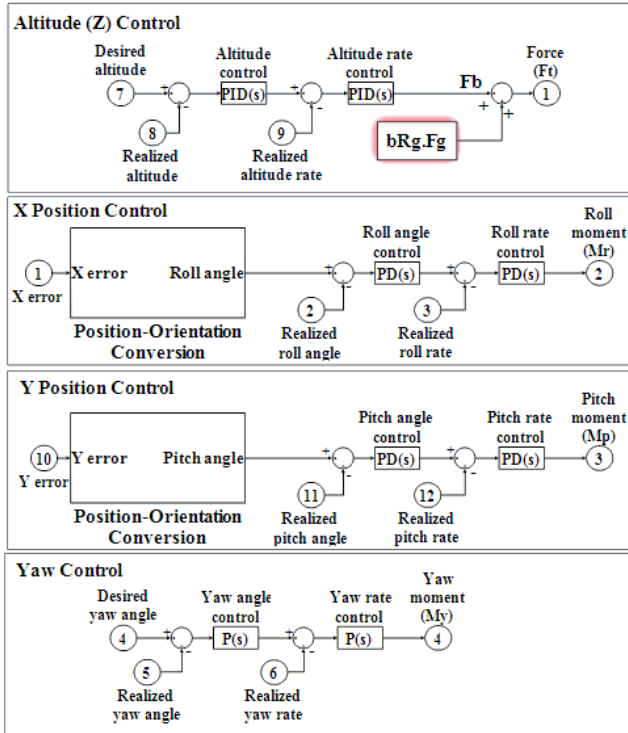


Figure 7. The proposed system control block diagram

Linear speed is limited to 3 m/s and maximum tilt angle is 45 degree of both UAV.

The simulation performed under the effect of disturbance force for three axes given in Figure 8. This force represents the effect of winds on the vehicle.

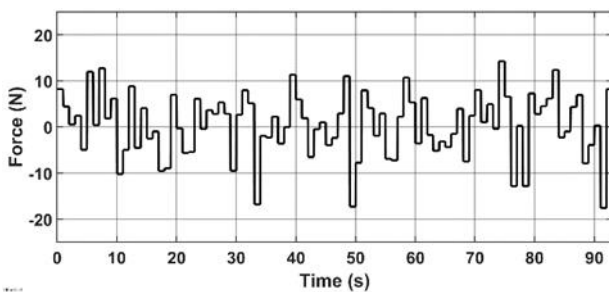


Figure 8. Disturbance effect

As can be seen from Figure 9 and Figure 10, the result of trajectory tracking simulation on three axes is obtained graphically for both models. The average of the root mean square (RMS) values of the position errors occurring in all three axes in the simulation were calculated as 0.915 m and 1.120 m for first and second model, respectively.

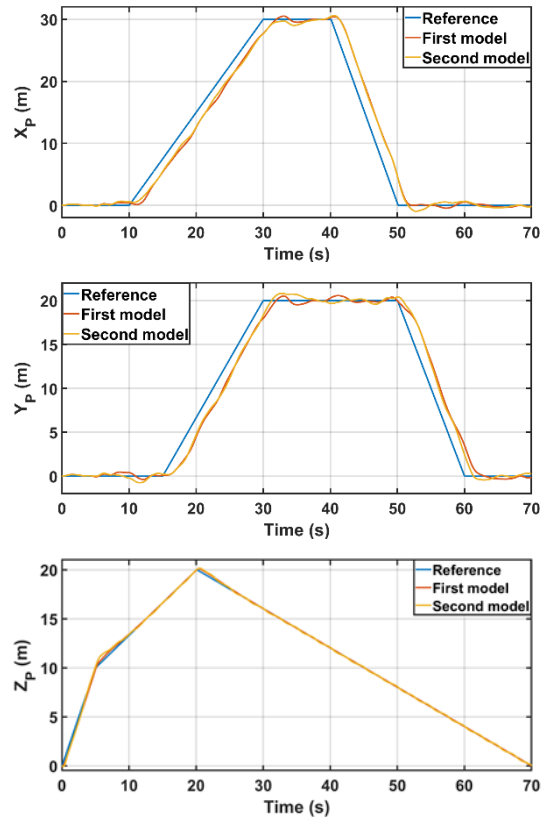


Figure 9. X, Y and Z axes tracking of dodecacopter models

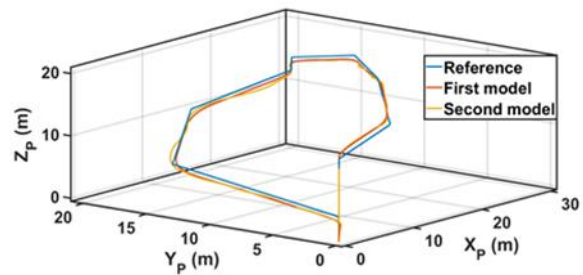


Figure 10. 3-D trajectory tracking of both model

Besides, the maximum and rms values of the position errors occurring in three axes are given in Table 2. At the same time, mean values of the position errors are given in the same table.

Table 2. Numerical results of both model

		Position errors [m]			
		First model		Second model	
		Max	RMS	Max	RMS
Axis	X	4.54	1.54	4.62	1.96
	Y	2.03	1.08	2.21	1.19
	Z	0.54	0.12	0.76	0.21
Mean		2.37	0.915	2,53	1.120

4. Conclusion

This study is based on the modeling and simulation of two different twelve rotor UAV with non-traditional

configurations. The two different UAV models with 12 motors have been proposed for high load carrying capacity. While the motors of the first of these two different models are placed in the same plane, the second model's motors are divided into two separate planes, upper and lower. The simulation study performed in MATLAB environment for both models, PID controllers with the same parameters were used.

According to the results, the trajectory tracking performances in terms of position errors of both models were close, while the error in the second model was found to be less than the other. The results were found satisfactory.

Since the angle between the rotors in the first model is narrower, if both models use the same size propeller, the arm length of the first model must be more. This can be said as a negative situation, since the size of the first model will require more than the second.

This proposed two different type multi-rotor air vehicle model could be utilized in areas where high lifting capacity is important. At the same time, it is thought that it can give an idea to different UAV designs.

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