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Araştırma Makalesi – Research Article

Investigation of the Impact of Different Material Types on Quadcopter Ascension Performance

Farklı Malzemelerin Quadcopterde Yükseklik Performansına Etkisi

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ABSTRACT

This study investigates the impacts of various materials depending on the quadcopter's determined flight altitude reference. On Solidworks, three different material groups are assigned to the body of the quadcopter design created for this study, these are polystyrene, carbon fiber reinforced epoxy composite, and 7075 aluminum alloy. Regardless of the body material, polystyrene material is used in the arms carrying the wings and engines. Mass calculations are made in the quadcopter according to the determined materials. In line with the calculations, a fuzzy logic-based PD controller is used for quadcopter altitude control. The input-output gains of the fuzzy logic-based PD are adjusted manually according to the reference height values and tests are carried out in the Matlab-Simulink environment. Four different values are determined for the test reference heights; these are 1 m, 1.5 m, 2.5 m, and 5 m, respectively. The test results show that the model with the polystyrene material in the body part is more successful than the other materials for the specified reference values.

Anahtar Kelimeler- Quadcopter, Fuzzy Logic, Matlab, Composite, 7075 Aluminum

ÖZ

Bu çalışmada quadcopter yüksekliğine çeşitli malzemelerin etkileri incelenmiştir. Yapılan quadcopter tasarımının gövdesi üzerine polisten, kabon elyaf takviyeli epoksi kompozit ve alüminyum 7075 alaşımı SolidWorks ortamında eklenmiştir. Kanatları ve motorları taşıyan kollar da ise gövde malzemesinden bağımsız olarak polistren kullanılmıştır. Eklenen malzemelere göre quadcopterde kütle hesaplamaları yapılmıştır. Bu hesaplamalar ışığında quadcopter yükseklik kontrolü için bulanık mantık tabanlı PD kontrolör kullanılmıştır. Bulanık mantık tabanlı PD'nin giriş-çıkış kazançları referans yükseklik değerlerine göre elle ayarlanıp Matlab-Simulink ortamında deneyler gerçekleştirilmiştir. Deneylerde referans yükseklikleri sırasıyla 1 m,1-0.5 m 2.5 m ve 5 m olmak üzere dört farklı değer kullanılmıştır. Yapılan deney sonuçları göstermiştir ki, gövdesinde polistren malzeme kullanılan dron modeli kullanılan referans değerlerinde diğer malzemelere göre başarılı sonuçlar vermiştir.

Keywords- Quadcopter, Fuzzy Logic, Matlab, Kompozit, 7075 Alüminyum

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I. INTRODUCTION

Quadcopters are known as drones with four rotors. Recently, unmanned aerial vehicles have been widely used for military and civil purposes with their aerodynamic structure and size. S. Chen et al. used unmanned aerial vehicles for observation [1]. Gadda et al. preferred unmanned aerial vehicles for border protection duty [2]. S. Zhao et al. used an unmanned aerial vehicle to perform the cargo and transportation tasks [3]. Murthy and Meta Dev Prasad performed a search and rescue operation with an unmanned aerial vehicle [4].

With the nonlinear structure of unmanned aerial vehicles, studies have been carried out with various control structures in the literature. A. Tayebi and S. McGilvray conducted a quadcopter study with a classical PID controller [5]. F. Candan et al. performed position control of nano-quadcopter with fuzzy logic-based PID [6]. K. Menfoukh et al. controlled the unmanned aerial vehicle with artificial neural networks [7]. S. Bouabdallah et al. applied LQR and PID structures on quadcopter [8]. K. Alexis et al. used the model predictive control method for altitude and position control of quadcopters [9]. F. Santoso et al. worked on the quadcopter with H^∞ method [10].

Fuzzy logic, which is one of the intelligent control systems, is a system that imitates the ability of human beings to think and make decisions. Fuzzy logic was introduced to the literature by Lötfi Zadeh in 1965 [11]. In the fuzzy logic system, there are “IF-THEN” rule structures that contain linguistic terms. Fuzzy logic systems have been successfully applied in nonlinear and complex systems. İ. Şahin and T. Kumbasar used fuzzy logic to design a pursuit-evasion game in Unity 3D game environment [12]. S. E. Ovur et al. solved the inverted pendulum problem with a fuzzy logic system [13]. E. Armağan and T. Kumbasar designed a fuzzy system for autonomous vehicle control [14]. A. Yılmaz et al. performed a risk analysis for cancer disease using the fuzzy logic method [15]. S. Mondal and D. K. Pratihar used the fuzzy logic method in their mobile robot projects [16]. S. A. Biyouki et al. designed a diagnostic system consisting of fuzzy logic and an expert system [17].

Today, the importance of material in quadcopter design is increasing day by day. In this study, polystyrene, carbon fiber reinforced epoxy composite, and 7075 aluminum alloy, all of which can be used in quadcopters, are used. These three materials are all light and durable, which is the most required specification for unmanned aerial vehicles such as quadcopters. Sudhin et al. compared the mechanical properties of carbon fiber reinforced thermoplastic and thermoset composites used in aerospace applications. In the study, polyether ketone (PEK) was preferred as thermoplastic, and epoxy resin was preferred as a thermoset. In both composite structures, 60% carbon fiber was used. As a result of the tensile test, the tensile strength of the polyether ketone-carbon fiber (PK-CF) composite structure was measured as 425 MPa, and for the epoxy-carbon fiber (E-CF) composite structure, it was 311 MPa. In addition, the tensile density factor of the polyether ketone-carbon fiber composite was calculated to be 10% higher than that of the epoxy carbon fiber composite. In line with these data, the glass transition temperature of the PK-CF composite was higher [18]. In their research, Mikhail et al. observed changes in improved mechanical properties by adding nano-sized carbon nanotubes and chopped carbon fibers to the structure of epoxy-carbon fiber composites. Within the scope of the study, 0.5-5 wt% of milled carbon fiber and 0.1-0.5 wt% of single-wall carbon nanotubes were added to the epoxy-carbon fiber composite. As a result of the experiments, 8.6% increase in static tensile strength and a 14% increase in flexural strength were observed. Additionally, it was determined that there was a significant improvement in fatigue durability [19]. For his thesis, Kılıçtek produced nano alumina reinforced hybrid composites (carbon fiber-aramid fiber) with 3, 5, and 7 layers using the vacuum infusion technique. The mechanical properties were compared according to the number of layers by adding 2% by weight and 40 nm of size nanoalumina into each composite material. As a result of the experiments, it was determined that the tensile strength and fracture toughness of the composite material increased as the number of layers increased [20]. In their study, Afaf et al. mentioned the importance of aluminum alloys in the aerospace industry. They emphasized that important mechanical properties can be changed and combinations with low weight and high strength can be obtained by means of aluminum alloys [21]. Johannes et al. conducted research on the stabilization of the 7XXX aluminum alloy series. This alloy series consists of Al-Zn-Mg-(Cu) content. The alloy has been pre-aged at various low temperatures to improve its natural aging and poor forming properties at room temperature. As a result of this process, the natural aging process of AA7021 is prevented and a more stable condition with lower hardness is provided. In the AA7075 alloy, the paint bake response was improved and the yield strength remained only below 2% [22]. Ahmad et al. studied the material optimization of the quadcopter body frame with the help of finite element analysis based on vibration. After designing the body frame in Creo 2, they simulated it in Ansys 16.2 to predict possible failure zones. In this study, three different materials were selected for the body frame: aluminum alloy, copper alloy, and stainless steel. As a result of the analysis, it was seen that the body using aluminum alloy gave better results than the other two materials [23]. Taking aerospace applications as a reference, Kauser et al. investigated the impact of carbon nanotube, graphene oxide, clay nanofiller, and graphite materials by adding them into polymer materials such as polystyrene, polypropylene, polyurethane, polyaniline, and polyamide [24]. Xu et al. added alumina, silica, and clay as fillers to polystyrene-based shape memory composite materials and investigated how these additives affect the mechanical and thermal properties of the composite material [25].

In the current study, the effects of polystyrene, carbon reinforced epoxy composite, and 7075 aluminum alloy materials used in the body part of the quadcopter on the altitude performance are investigated. Polystyrene material fixing is simulated for the arms carrying the wings and motors.

Small, unmanned quadcopters are powered by electric motors driving fixed-pitch propellers. This multi-rotor propulsion system provides the lift, thrust, and control of the quadcopter, which results in a significant demand for electric power. The mass changes that will occur due to the different material densities used in the quadcopter body are quite small. For this reason, the same motor was tried and simulated for all material structures in the study. After assigning the materials to the body, mass calculations are made for each material group. According to these mass calculations, a quadcopter model is created in the Matlab-Simulink environment for reference heights. A fuzzy logic-based PD controller design is carried out in order to perform the height performance analysis of the created model. Finally, a cost analysis including all the materials used in the study was made.

II. MATERIALS AND METHODS

A. Quadcopter Model

In this section, the equations of motion and basic properties of the quadcopter are given. Figure 1 shows the position and direction of an example quadcopter. Quadcopter movement consists of two subsystems. These are the linear subsystem (x,y,z) and the rotational subsystem (roll, pitch, and yaw). The quadcopter in Figure 1 has four independent rotors. While rotors 1 and 3 rotate clockwise, rotors 2 and 4 rotate counterclockwise. In this case, the total torque around the z-axis is equal to zero.

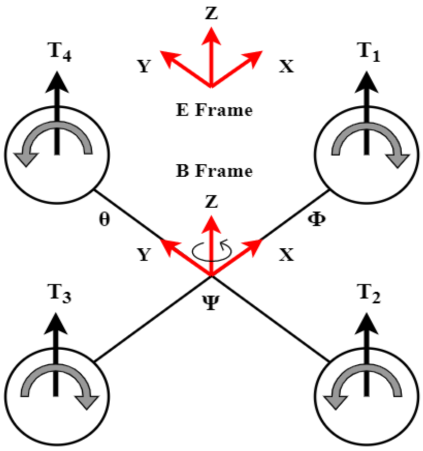

Figure 1. Position and direction of quadcopter

In Equation 1, ϕ,θ,ψ angles represent roll, pitch, and yaw angles, respectively, and .I_{xx},I_{yy},I_{zz} correspond to the moments of inertia of the respective axes.

$$\ddot{X} = (\sin\psi \sin\phi + \cos\psi \sin\theta \cos\phi) + \frac{U_1}{m} \tag{1}$$

$$\ddot{Y} = (-\cos\psi \sin\phi + \sin\psi \sin\theta \cos\phi) + \frac{U_1}{m} \tag{2}$$

$$\ddot{Z} = -g + (\cos\theta \cos\phi) + \frac{U_1}{m} \tag{3}$$

$$\phi^{\cdot\cdot} = ((I\_yy - I\_zz\,)\,\theta^{\cdot}\psi^{\cdot} - J\_r\,\theta^{\cdot}W\_r + U\_2)/Ixx \tag{4}$$

$$\theta^{\cdot\cdot} = ((I\_zz - I\_xx\,)\,\phi^{\cdot}\psi^{\cdot} - J\_r\,\phi^{\cdot}W\_r + U\_3)/Iyy \tag{5}$$

$$\ddot{\phi} = \frac{(I_{xx} - I_{yy})\dot{\phi}\dot{\theta} + U_4}{I_{zz}} \tag{6}$$

Control inputs in the quadcopter are given in Equation 2. Total thrust on the Z axis is indicated as U_1, and roll, pitch, and yaw control points are indicated as U_2, U_3, and U_4, respectively. Here, k_a represents the aerodynamic force, k_m the moment constant, and Ω_i the angular velocity of the i engine.

$$U_1 = k_a(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2) \tag{7}$$

$$U_2 = k_t(-\Omega_2^2 + \Omega_4^2) \tag{8}$$

$$U_3 = k_t(\Omega_1^2 - \Omega_3^2) \tag{9}$$

$$U_4 = k_m(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2) \tag{10}$$

In this study, the necessary system model for the altitude control of the quadcopter is created with Equation 3. Equation 3 represents the acceleration of the quadcopter in the z-axis. Taking the integrating of this equation twice gives the quadcopter's position on the z-axis, that is, its height.

$$\ddot{Z} = -g + (\cos\theta\cos\phi)\frac{U_1}{m} \tag{11}$$

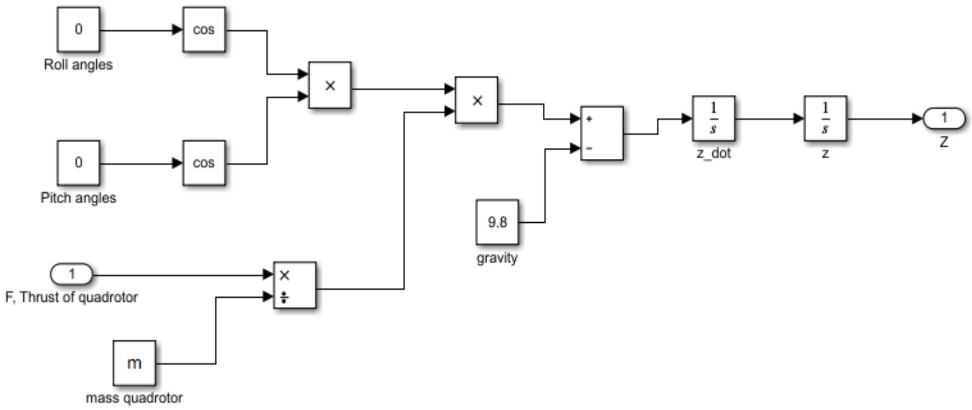

Figure 2. Shows the quadcopter model designed for altitude control in the Simulink environment.

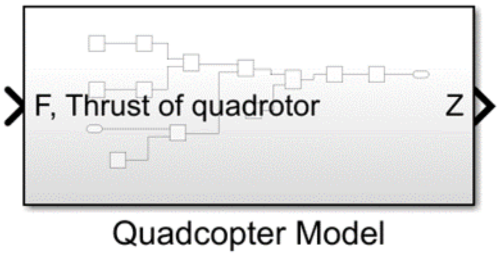

Figure 3. Quadcopter Matlab/Simulink model

Three different material groups are tested on the quadcopter model, these are polystyrene, carbon fiber reinforced epoxy composite, and 7075 aluminum alloy. Gravity is considered as 9.81 m/s^2 throughout the study. The mass of the quadcopter varies according to the selected material. A fuzzy logic-based PD controller is designed for altitude control in the quadcopter model created with various materials.

B. Fuzzy System

Systems containing fuzzy sets and the mathematical structure associated with them are called fuzzy systems. The internal structure of the fuzzy system is shown in Figure 4. There are four units in the internal structure of a fuzzy system. These are fuzzifier, fuzzy inference mechanism, fuzzy rule base, and defuzzifier units, respectively. The fuzzifier is the unit that transforms the real-valued system input (crisp input) into fuzzy sets and thus allows them to be evaluated in the fuzzy inference mechanism. The fuzzy inference mechanism produces fuzzy sets at its output in accordance with the "IF-THEN" rules defined in the fuzzy rule base. The obtained fuzzy sets are given as input to the defuzzifier unit and converted to real numbers (crisp output) at the output [26].

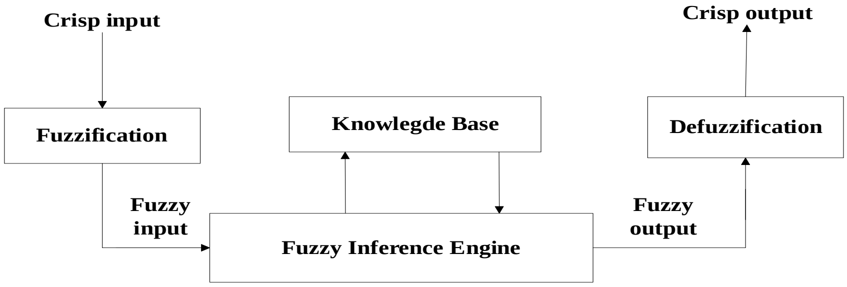

Figure 4. The internal structure of the fuzzy system

A fuzzy logic-based PD system is designed for height control for the model structure of the quadcopter and it is presented in Figure 5.

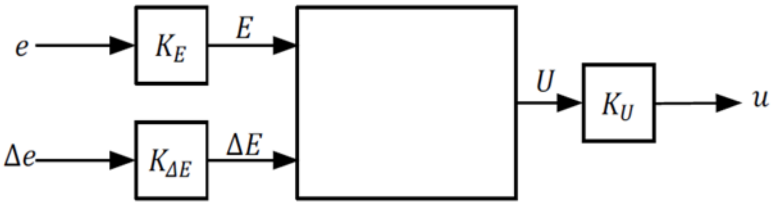

Figure 5. Fuzzy PD controller design

In this study, we designed altitude quadcopter model which has double integrated system. For this reason, we use the fuzzy PD controller to control the quadcopter model. The inputs of the fuzzy PD system are the error (e) and the variation rate of the error (Δe), and the output is the torque value (u) that is applied to the quadcopter. The u value specified here is equal to U1 shown in Equation 2. Fuzzy system designed with a 3x3 rule base as shown in Fig.6.a. The antecedent Membership Functions (MFs) are characterized with triangular MFs as given in Fig.6.b. The linguistic fuzzy variables being Negative, Zero, and Positive are abbreviated as "N, Z, P", respectively. The crisp singletons are defined as follows: NB: Negative Big, NM: Negative Medium Z: Zero, PM: Positive Medium, PB: Positive Big as shown in Fig.6.c. Fuzzy systems uses and employs the product implication and the center of sets defuzzification method.

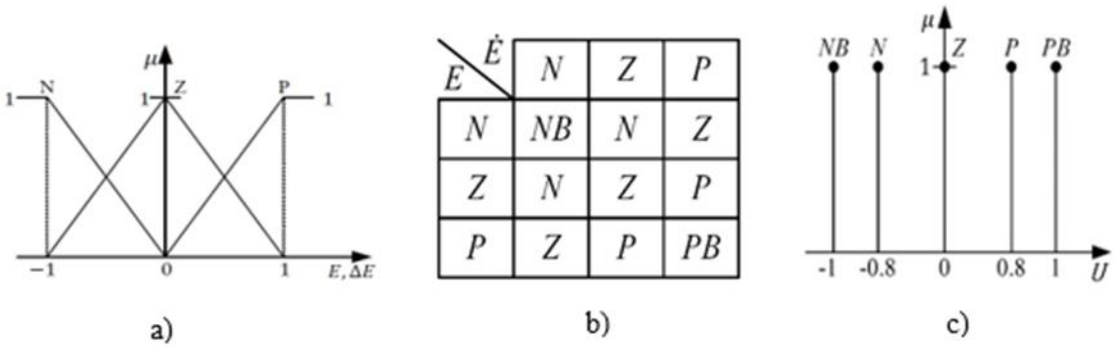

Figure 6. a) input membership function, b) rule structure and c) output membership function of the fuzzy PD system

C. Material Properties

Polystyrene, carbon fiber reinforced composite, and aluminum alloy materials are preferred for the body of the quadcopter. Polystyrene material is chosen for the arms of the quadcopter shown in Figure 7, and this material is kept constant for all three determined bodies. These materials are assigned to the body and arms of the quadcopter in the Solidworks program one by one, and the masses to be used in the analyzes are calculated.

Figure 7. Quadcopter model for the material assignment

1) Polystyrene material

Polymers are one of the most used engineering materials today. Because of the increase in the world population and the developments in science and technology, a significant increase is observed in the use of polymers [27]. Polymers, also known as plastic materials, are widely used in daily life, and they are also used in industry, packaging, furniture, construction, electronics, agriculture, and transportation. To meet this increasing demand, approximately 322 million tons of plastic products are produced worldwide [28]. There are two types of polymers, thermoplastics, and thermosets [29]. Thermoplastic polymers are preferred as the raw material of many products used in daily life and industry [30].

Polystyrene is an important industrial thermoplastic due to its good mechanical properties, low cost, and light weight [31,32]. In addition to being used as an insulation material in the construction industry, it is also widely preferred in the production of food containers, packaging foam, compact discs, and disposable utensils. According to 2013 data, approximately 21 million tons of polystyrene products were produced in the world [31]. Polystyrene is a thermoplastic with two different polymer chain structures, amorphous and crystalline, and it is brittle due to this structure [33]. The chemical structure of the polystyrene material is shown in Figure 8. Polystyrene material is a synthetic aromatic polymer with high molecular properties consisting of monomer styrene. It can be in solid or foam form. Due to its molecular structure, it can be hard and brittle. It also has a low melting temperature and poor resistance to water vapour [27]. While polystyrene materials have many superior properties, their biodegradable properties are quite bad. Although they are described as insoluble in nature according to some sources, these materials can dissolve in the natural environment, albeit very slowly [34].

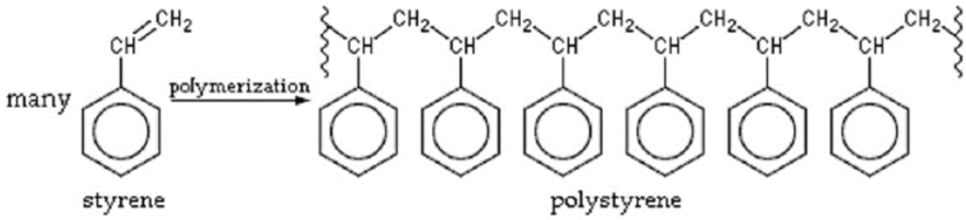

Figure 8. Schematic representation of the chemical structure of polystyrene [37]

2) Composite Material

Composite is defined as a combination of materials from the same or different groups in macro dimensions and having better properties than its component materials [35]. Composite materials consist of matrix and dispersed phases and are classified according to these phases. While the matrix is responsible for holding the reinforcement phase together and transmitting the load on the composite material to the dispersed phase, the dispersed phase is responsible for providing the desired properties from the composite material [36]. Composites have low density, high strength, good fatigue durability, design flexibility, and corrosion resistance [37]. Accordingly, it is used in many areas such as the automotive industry, ship industry, sports equipment, defense industry, space and aircraft industry [38]. Although glass fibers are generally used in composite applications due to their superior properties, carbon fibers are preferred more frequently in most advanced technological applications.

In this study, carbon fibers are preferred due to their light weight and high strength values. With the placement of the carbon fiber in the polymer matrix, the high strength value increases further and the hardness of the material also increases [39]. The carbon fiber composite material chosen in this study is Thornel Mat VMA, which is included in the Solidworks program. The general properties of this carbon fiber are given in Table 1.

Table 1. Properties of the Thornel Matte VMA carbon fiber.

Tensile strength	1400 MPa
Tensile module	170 GPa
Density	2.0 g/cm^3
Specific surface area	0.40 m^2/g

3) 7075 Aluminum alloy

Aluminum and its alloys are widely used materials in engineering applications [40]. Aluminum alloys of the 7XXX series are also called aluminum-zinc alloys. This series was developed by a Japanese company in 1943. The maximum zinc content in its chemical composition is between 5.1% and 6.1%. It is known that the superior features of the series are lightness, high corrosion resistance, and high specific power [41,42]. Because of these properties, aluminum alloys are widely used in the automotive, packaging, aerospace and aircraft industries [43].

7075 aluminum alloys of the 7XXX series have an important place in the industry. Although its general properties are the same as the series, the most important feature that distinguishes 7075 aluminum alloy from the others is that it allows the aging process and thus has excellent mechanical properties [44]. In addition, the 7075 series is widely used in the automotive industry, defense industry, aircraft and yacht industry, with its superior properties such as low density, high strength, high fatigue durability, toughness, and ductility [44, 45].

D. Cost Analysis

The gross weights of the composite, polystyrene, and Al7075 alloys used in the Quadcopter model. The designed model aims to use four motors and operate them under 12 V voltage. In this study, the proper material selection was investigated to enable Quadcopters to achieve the best possible reference value at different heights. Moreover, cost has been considered as an important parameter in the selection of these materials. The price of the components used in the designed Quadcopter model is given in Table 2.

Table 2. Quadcopter components and cost estimation.

No.	Hardware components and materials	Price ($)
1	Electronic Speed Controller M30-A	12.99
2	Lithium-Polymer 3000 mAh (milliamp-hour), 12 volt	38.90
3	Ardupilot 2.8 mega flight controller	115.78
4	4xServo MotorSG90	10.52
5	3-Axis: Accelerometer and Gyroscope Module	36.84
6	Polystrene	38.80
7	Epoxy resin	14.34
8	Carbon fiber 600g/m^2 12k-twill	42.03
9	Al7075 alloys per kg	2.55

III. RESULTS

In the study, three different material groups, polystyrene, carbon fiber, and aluminum, are preferred while creating the quadcopter model. These materials are applied to the body parts of the quadcopter model. The mass of the quadcopter body models made of these three materials are m_p=0.111 kg, m_k=0.147 kg, and m_a=0.178 kg, respectively. Four different tests are carried out on each quadcopter model. Every test lasted ten minutes and as given the performance index which is IAE (Integral Absolute Error) of different material of quadcoper models. In the first test, the ascension of the quadcopter models to the 1-meter reference is tested. The result of this test is shown in Figure 9. Performance index of the 1 meter test as shown in Table 3.

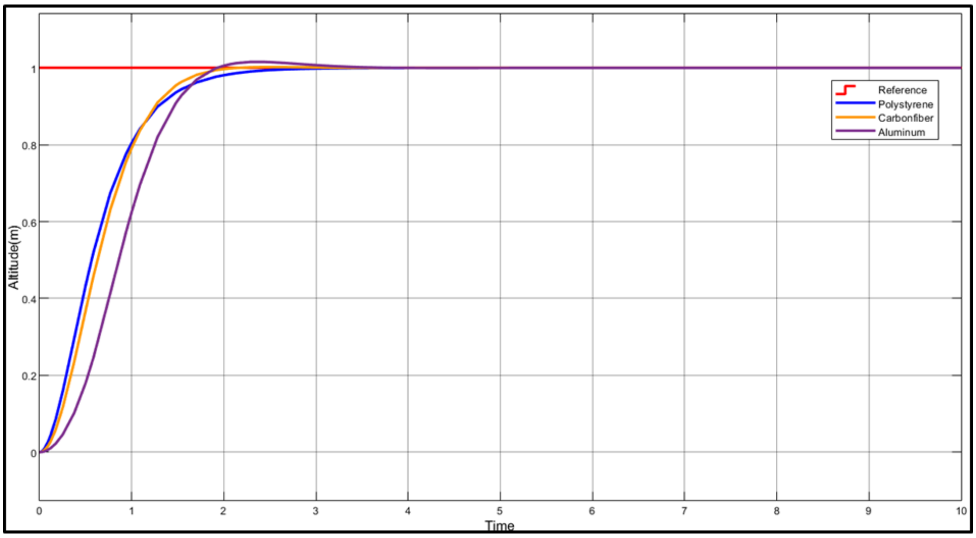

Figure 9. Test result for 1-meter reference

Table 3. Performance index of the 1 meter test

Material	IAE
Polystyrene	0.6727
Carbonfiber	0.6949
Aluminum	0.9048

In this test, the input and output gains of the fuzzy logic-based PD controllers used in the quadcopter models are the same, and K_E=1.2, $K_{\Delta E}$=0.75, and K_U=1'. These values are set manually. The quadcopter with a polystyrene body material ascended to the specified reference altitude faster than other quadcopter models. The quadcopter model with carbon fiber material ascended later than the polystyrene material but settled at the reference in time. The quadcopter model with aluminum material settled late at the reference by exceeding it.

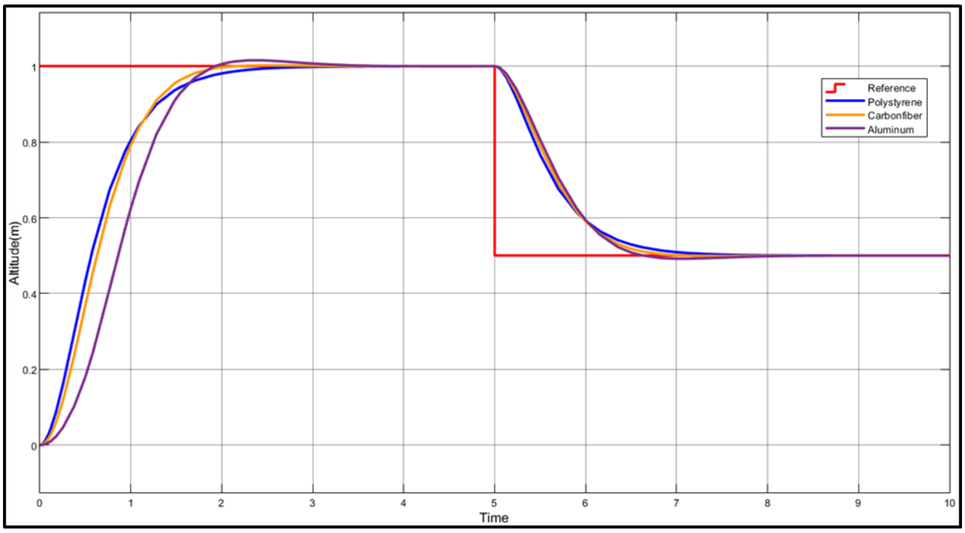

Figure 10. Test result for 1-0.5 meter reference

In the second experiment shown in Figure 10, the quadcopter models were remained at 1-meter reference during the first 5 seconds and after that, descended to 0.5 reference. Performance index of the 1-0.5 meter test as given in Table 4. It was observed that the quadcopter that settled at the reference the fastest after 5 seconds was the model with the aluminum body. Since this model is heavier than other quadcopter models, it descended to the 0.5-meter reference faster than the others with the impact of gravity. The input and output gains of fuzzy logic-based PD controllers used in quadcopter models are the same, and K_E=1.2, $K_{\Delta E}$=0.75 and K_U=1'.

Table 4. Performance index of the 1-0.5 meter test

Material	IAE
Polystyrene	0.9964
Carbonfiber	1.019
Aluminum	1.241

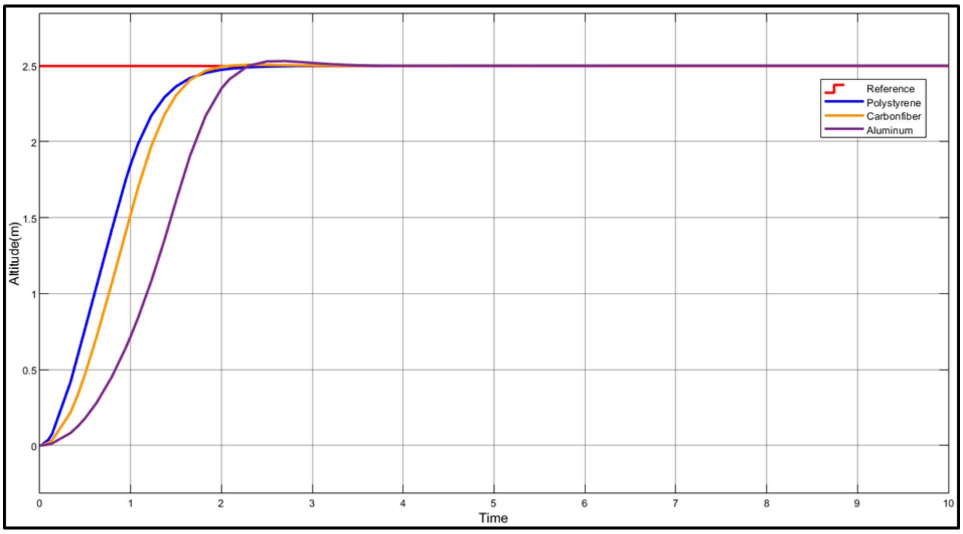

Figure 11. 2.5-meter test result

In the third test shown in Figure 11, the quadcopter models were ascended to a height of 2.5 meters. Performance index of the 2.5 meter test as shown in Table 5. In this test, the input and output gains of the fuzzy logic-based PD controllers used in the quadcopter models are the same, and K_E=0.95, $K_{\Delta E}$=0.45 and K_U=2'. As can be seen in the figure, the quadcopter model with polystyrene body settled at the reference faster. The quadcopter model with aluminum body was the last to settle at the reference among other material groups.

Table 5. Performance index of the 2.5 meter test

Material	IAE
Polystyrene	1.903
Carbonfiber	2.231
Aluminum	3.216

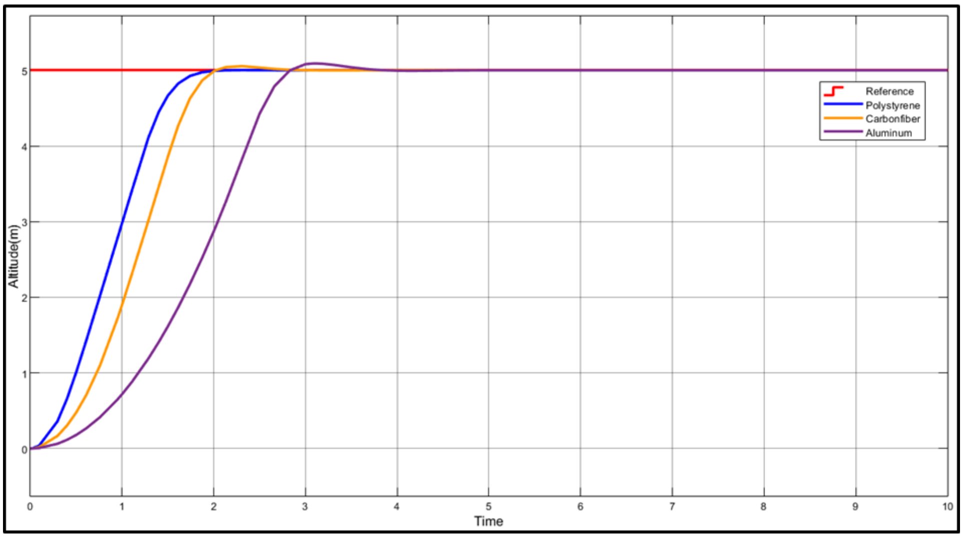

Figure 12. 5-meter test result

In the final test, which is shown in Figure 12, the quadcopter models were ascended to a height of 5 meters. Performance index of the 5 meter test as given in Table 6. In this test, the input and output gains of the fuzzy logic-based PD controllers used in the quadcopter models are the same and K_E=0.75, $K_{\Delta E}$=0.25 and K_U=4. The results of the test show that the quadcopter, whose body is designed from polystyrene material, settled at the reference value in 2 seconds, the carbon fiber body in 3 seconds, but by exceeding it first, and the aluminum body in 4 seconds, also by exceeding it.

Table 6. Performance index of the 5 meter test

Material	IAE
Polystyrene	4.429
Carbonfiber	5.674
Aluminum	8.895

IV. CONCLUSION

In this study, the impact of different materials used in quadcopter design on quadcopter ascension performance is investigated. The body of the quadcopter is made with polystyrene, carbon fiber reinforced epoxy composite, and 7075 aluminum materials. Experiments are carried out at various reference values. When the results of the analysis are examined;

- It has been determined that the fastest material to settle at the reference values without exceeding them is polystyrene material due to its low density. For this reason, polystyrene is thought to be the best material for arriving at the reference among the materials used in the study.
- It has been determined that the quadcopter with polystyrene body has the best ascension curve.
- In the tests, the polystyrene material settled at reference levels without exceeding them.
- The carbon fiber reinforced epoxy composite material settled at the reference height by exceeding it.
- It is also observed that the exceeding level of the aluminum alloy was higher than that of the composite material.
- The first material to reach the reference value of $1 - 0.5$ m was aluminum alloy due to its high density.
- When the results of the study with a reference value of 1 m are considered, it has been determined that the material with a mass of 0.111 kg, which is polystyrene, has reached the reference position first. When the other materials used are examined, it is seen that the material with a mass of 0.147 kg, which is carbon fiber, has reached the 1m reference value secondly. The Al7075 alloy with a mass of 0.178 kg, on the other hand, exceeded the reference value initially determined for a while and then descended and reached the reference value.
- In the study presented in Figure 10, the performance of quadcopter materials in both ascent and descent values was examined by taking two different reference values.
- During the second test, the reference value for the height was set to 1m, and the reference value for descent was set to 0.5 m.
- Upon examining the results presented in Figure 10, it can be observed that the quadcopter model with polystyrene material achieved the 1m reference value with the lowest error rate of 0.9964. It also reached the descent reference value with the lowest error rate. During this analysis, the Al7075 alloy exceeded the reference value during ascent performance and, due to its higher weight, made a rapid descent under the effect of gravity during descent. However, it reached the desired reference value again after dropping below the 0.5 m reference value.
- In Figure 11, the reference value was increased to 2.5 m to better understand the performance of the quadcopter in terms of height.
- Polystyrene reached the 2.5 m reference value with the lowest error rate of 1.903. The other materials, carbon fiber and Al7075 alloy, positioned themselves at the reference value with error rates of 2.231 and 3.216, respectively.
- Finally, the selected analysis height value is 5 m.
- The best height performance at the 5 m reference value was also observed in the quadcopter model that uses polystyrene material. With the reference height increasing from 2.5 m to 5 m, the error rate of carbon fiber has increased by more than two-fold, reaching 5.574, and as a result, like Al7075 alloy, it exceeded the reference value and then descended to the 5 m height.
- When the height performance of the quadcopter is examined, it is observed that the polystyrene material reached the specified reference values with the lowest error rates of 0.6727, 0.9964, 1.903, and 4.429, respectively.
- Carbon fiber, with error values of 0.6949, 1.019, 2.231, and 5.674, has reached the reference values as the second material after polystyrene in terms of altitude performance.
- Al7075 alloy has reached the reference values as the third with error rates of 0.9048, 1.241, 3.216, and 8.895 during the analysis of quadcopter's height performance.

- The cost analysis of components and materials that can be used in this study is also included in addition to the height analyses performed.
- According to the material cost analysis, AL7075 alloy has the most affordable price, but in terms of height performance, it is not highly recommended in terms of price-performance ratio.
- When both height performance and mass-based price calculation are taken into account, polystyrene materials can be selected as the most suitable material in terms of price-performance ratio.

When the test graphics obtained at the reference values are examined, it has been determined that the material that gives the best results in terms of settling at the reference, ascension, and descent is polystyrene material. In this study, it is concluded that the most important feature affecting the ascension performance of a quadcopter is the density of the material.

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