DESIGN OF UAV CONTROL SYSTEM WITH FUZZY LOGIC CONTROLLER AND ITS IMPORTANCE IN THE ECONOMY

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***Introduction*.** This article presents a multi-rotor unmanned aerial vehicle control model using "Fuzzy-logic" in the Simulink environment of MATLAB software. As you know, UAVs are aerial robotics that are launched and lifted up with the help of several engines. The propellers of modern UAVs are generally located so that the thrust vectors created by them are parallel to each other and directed along the axis. Control of the movement of this vehicle in the plane is carried out by changing the pitch and/or roll angles, which depends on the changes in the rotational speeds of the respective engines. Figure 1 shows the pitch, rall, yaw rotations and thrust vectors of the quadcopter.

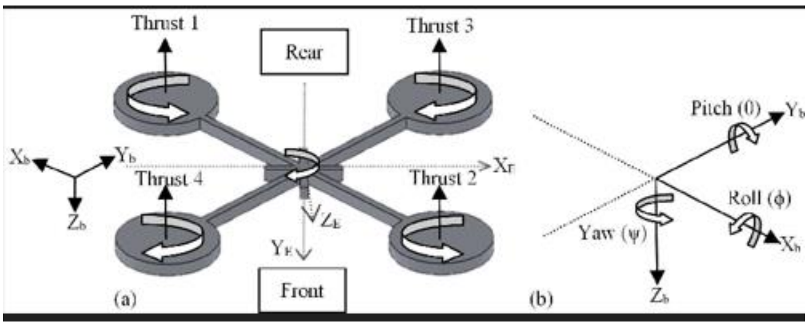


Figure 1. Pitch, roll, yaw for quadrotor

The great structural diversity and multi-functionality of UAVs [Valavanis, 2015, 3015, Agrawal, 2013, 5] make their application possible in almost all sectors of the economy. UAVs are most widely used in the following areas:

• military-reconnaissance equipment that allows you to unobtrusively spy on the enemy's military facilities,

• police-as surveillance robots that allow you to control the surrounding area from the air,

• postal services - such as automated mail delivery systems monitored by Global Positioning System (GPS);

• rescue services - in the search of people, detection of fires in forests and other operations,

• video recording and operator-recording of various objects in elevated or difficult-to-access places or control of ground transport traffic,

• in agricultural-irrigation and fertilization works,

• supervision of small, medium and large industries, main gas pipelines and high-voltage power lines,

• emergency assistance,

• geological, etc.

Taking all this into account, it is necessary to have an accurate control model of the UAV, in order to avoid mechanical damage to valuable equipment as a result of failures. The average market values of popular drones are shown in Table 1:

Table 1. Drones and prices

Drone	Price ($)
DJI Mini 2	449
DJI Mini 3 Pro	759
DJI Air 2S	999
DJI Mavic 3	2029
Autel Robotics Evo Lite+	1049
Autel Robotics Evo Nano+	709
DJI Avata	1168

The presented values document the importance of a stable and secure system.

***Methodology*.** The article presents a drone control model using a fuzzy-logic controller, adopting the possibilities provided by MATLAB Simulink as a design method, in particular the Fuzzy-logic Toolbox[Krzysztof Olesiak. 2017, 169-177], creating an automated system for changing the input values of the membership function[Ag. Setiawan, En. Arumi, P. Sukmasetya, 2020, 3189-3203], previously presented in the interval. The existence of such a safe control system necessary for the safe and accurate flight of the drone. Mamdani's method was selected as Fuzzy Logic algorithm, and the input membership functions for error and derivative error were trimf and gasumf, respectively.

Literature review. The importance of drone management was discussed in the work [Haidari, Brown, 2016, 65-73], where the influence of drones on the USA economy is presented, a UAV management system using Fuzzy-logic is presented [Sureshkumar, Cohen, 2014,144-156] the mathematical model of the control system is presented in the article, in our case the work was performed according to the parameters of the DJI MAVIC PRO drone.

Scientific novelty. This article presents a real model of the UAV, that is, a control system was built based on the real values, in which the membership functions of the Fuzzy-logic controller were adjusted using the GUI interface designed by us, integrating the values given by the latter into the Fuzzy Inference system(FIS), obtaining the desired results through computer simulation.

The mathematical model of the system. In order to design the mathematical model of the system and later obtain the dynamics equations, first, it is necessary define the reference frames:

The body fixed frame ($O_B X_B Y_B$) whose center coincides with the center of gravity of the quadcopter.

The inertial reference frame ($O_I X_I Y_I$) relative to which the motions are described is the same as described with respect to the earth (Fig. 1) [Hubinský, Chovanec, 2014, 172-181].

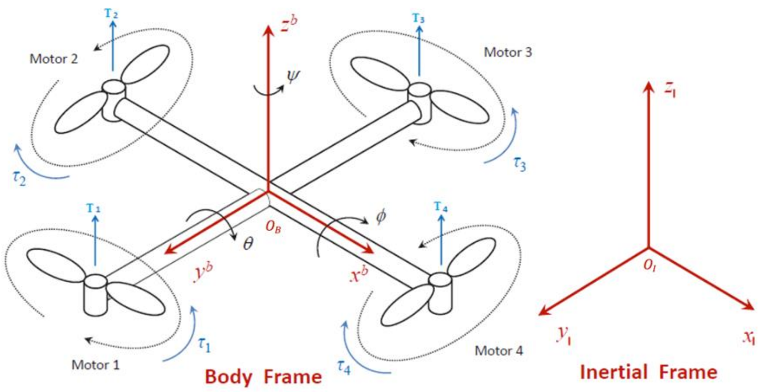


Figure 2. Inertial and body fixed frames

To obtain and apply the system dynamics equations, it is necessary to represent the transition from one reference frame to another ($O_B \rightarrow O_I, O_I \rightarrow O_B$), for which it is appropriate to apply Euler rotations with the corresponding rotation matrices. Euler angles are described as successive rotations about certain axes. The rotation about the Z axis of the inertial frame is described by the yaw angle ψ, from which the new P_1 frame is obtained. The rotation about the X_{P1} axis of the newly obtained P_1 frame is described by the roll angle, from which the new P_2 frame is obtained. The rotation about the Y_{P2} axis of the new P_2 reference frame obtained is described by θ, the pitch angle, which in turn coincides with the O_B reference frame rigidly attached to the quadcopter body. Thus, by means of $\psi - \varphi - \theta$ rotations, the transition from the inertial reference frame to the rigid body-fixed frame is described in the $z - x - y$ sequence (Fig. 2).

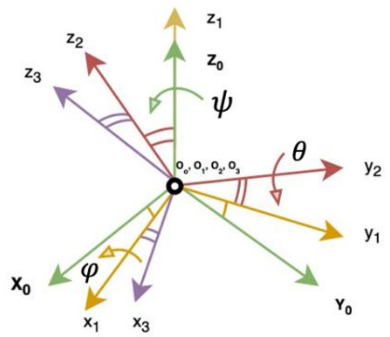


Figure 3. Euler rotations

As a result of the indicated successive rotations, the rotation matrix describing $O_B \to O_I$ transition has the following form:

$$R_{B\to I} = \begin{pmatrix} c\theta c\psi - s\phi s\psi s\theta & -c\phi s\psi & c\phi s\theta + c\theta s\phi s\psi \\ c\theta s\psi + c\psi s\phi s\theta & c\phi c\psi & s\psi s\theta - c\psi c\theta s\phi \\ -c\phi s\theta & s\phi & c\phi c\theta \end{pmatrix},$$

(1) where $cx = \cos(x), sx = \sin(x)$.

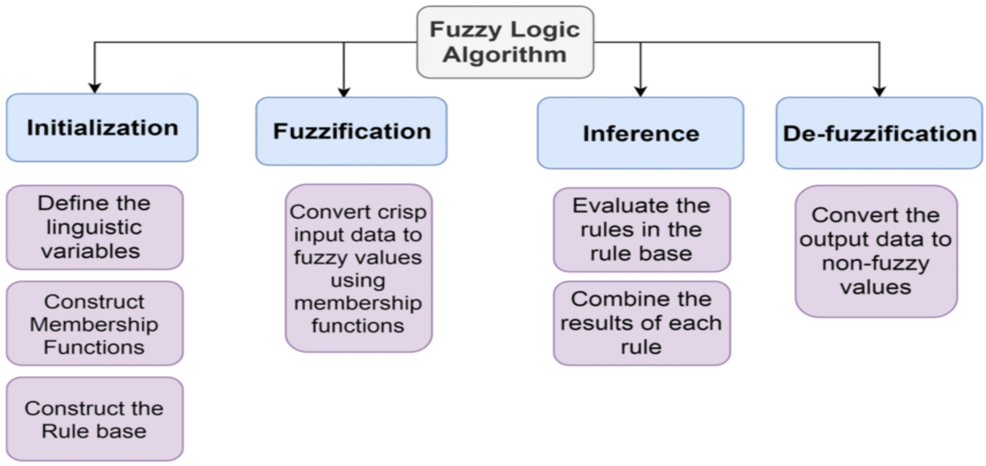


Figure 4. Fuzzy Logic Algorithm

Fuzzy logic controller. Fuzzy-logic controller works through Fuzzy sets and membership functions, where membership functions are transfer functions for input and output Fuzzy parameters. The work of fuzzy logic is divided into four parts, which are presented in Figure 4.

The block diagram of the Drone control system using Fuzzy logic control system presented in this article in MATLAB, Simulink environment is shown in Figure 5:

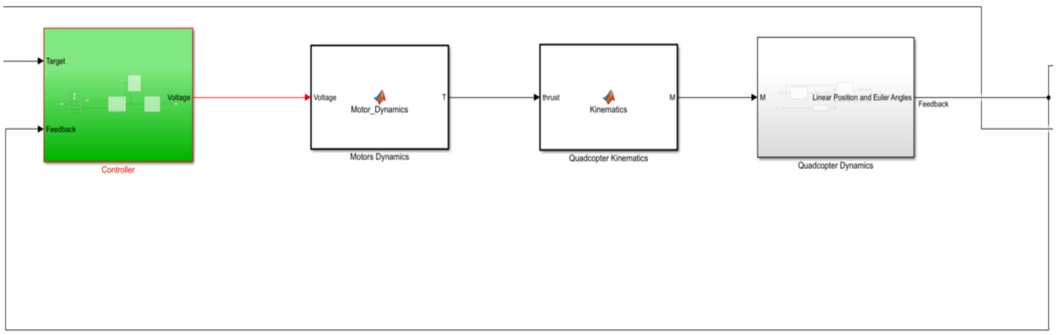
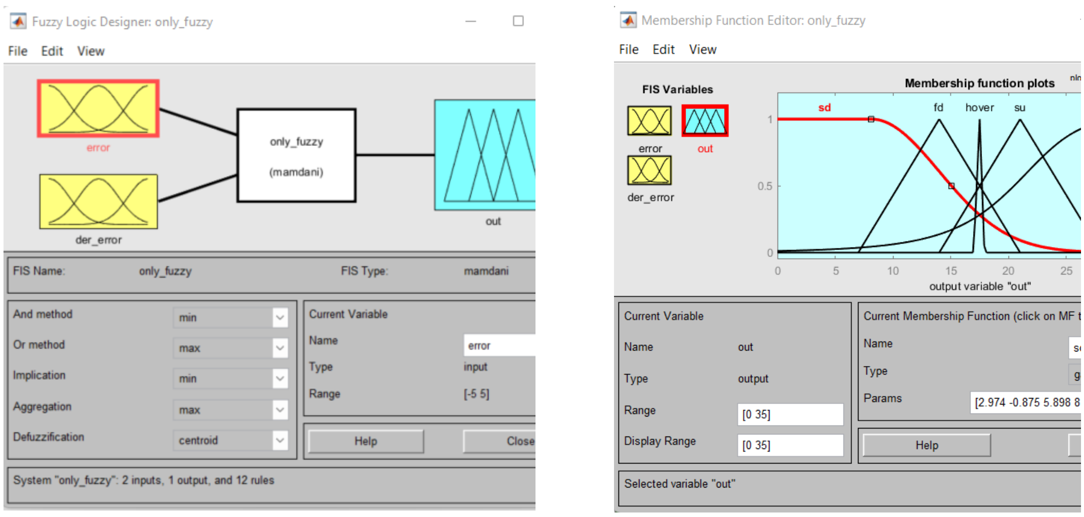


Figure 5. Drone's Control system

As can be seen from Figure 5, the control system has Controller, Motors Dynamics, Drone Kinematics, Drone Dynamics. The controller works with Fuzzy logic, whose Membership Functions are presented in Figure 6 a, b).



a) Input and output Membership functions b) Input and output Membership plots

Figure 6. Membership Functions

As can be seen from Figure 6, the input and output membership functions have a working range depending on the problem conditions. A GUI system has been designed for this work, which makes it possible to automatically obtain appropriate values of membership functions by selecting input or output values using a random algorithm, with different Fuzzy rules, to be closer to the presented requirements. The output of the preloaded graphical environment is shown in Figure 7:

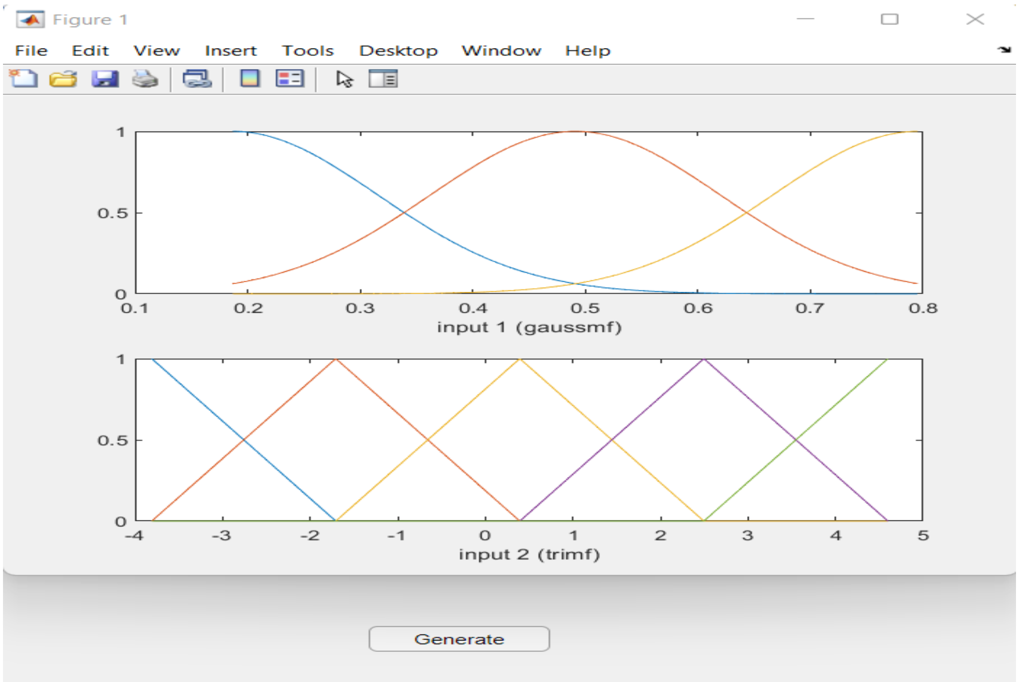


Figure 7. GUI results

Figure 7 shows only one of the working iterations of the designed GUI system, every time after click the Generate button, a new value of the membership functions is created in the predefined range, which automatically changes the Fuzzy logic controller of the Drone. the work, observing the most accurate starting value.

Results obtained. The working result of the designed GUI system is presented in Figure 7 above, where it is also possible to select the Fuzzy Logic algorithm by changing the values of the membership functions. The output value of the real-valued control system operating with the designed Fuzzy logic controller is shown in Figure 8.

It can be seen from Figure 8 that the control system working with the tuned fuzzy logic controller using the GUI adjusts the flight according to the preselected value of Z = 4.5m in T = 1.5 s.

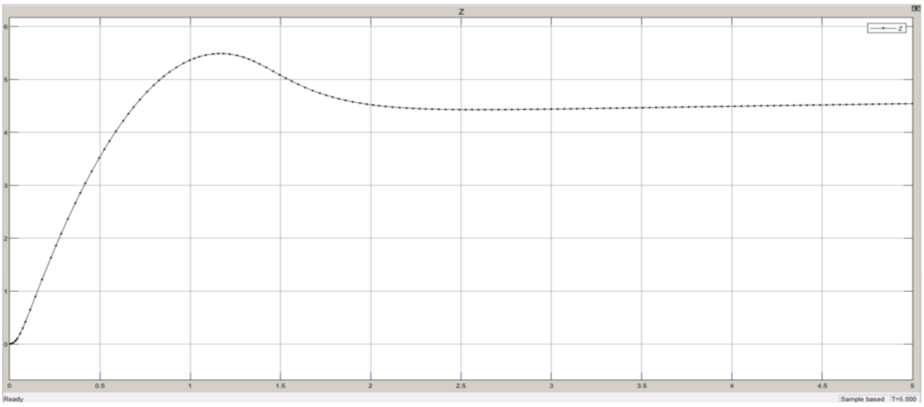


Figure 8. Final result of Z

Conclusion. This article presents one of the issues of high economic importance: Drone control system with fuzzy logic. The Matlab Simulink tool was used for the design of the control system, and a new system designed by the authors for the autotune of the Fuzzy logic controller. As a result of the work done, a control system corresponding to the parameters of one of the most popular drones, DJI MAVIC PRO, was produced, which is fully applicable in real conditions. Working outside of classical models, the control system with Fuzzy logic controller is useful and applicable.

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This article presents a model of the control system of a multi-rotor Unmanned aerial vehicle (uav) using Fuzzy logic controller. During the execution of the work, the Simulink environment of the MATLAB software system was used as a tool. As it is known, multi-rotor drones have a clear place in the modern world and are used in almost all areas of the economy, that is why a designed control system is a necessity. During the work, membership functions were calculated and defined, the adjustment of which was made by means of an automatic adjustment tool created in the form of a graphical interface, which selects independent values in the defined range, giving the Fuzzy inference system as an input. Mamdani fuzzy method (if and then) was selected as Fuzzy logic algorithm. At the end of the article, the results obtained from the designed graphic interface and control system are presented.