Design of Fuzzy Controller for Hexacopter Position Control

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Abstract. The paper deals with the design of a fuzzy controller for controlling the position of a hexacopter represented by a simulation model in Gazebo robot simulation environment, which in terms of control presents a highly nonlinear system with 6 degrees of freedom. The fuzzy controller design was based on the pilot´s experience and on analysis of experimental data collected during a controlled hexacopter flight, without the knowledge of its structure and parameters. The fuzzy controller properties were verified by real time experimental measurements, with sampling time 10 milliseconds. The obtained results have confirmed good dynamic properties of the PI fuzzy controller, which can in future be also applied in a real physical hexacopter model.

Keywords: Fuzzy, Control, Hexacopter, Gazebo.

1 Introduction

The research and development of unmanned aerial vehicles offers many opportunities for effective application of intelligent control methods [1, 2, 3, 4, 5, 6]. Issues related to unmanned aerial vehicles are numerous and can in general be divided into smaller areas of interest such as sensory system development, 3D modelling, mathematic modelling and simulation and control [7]. It is the area of modelling and control that is suitable for the application of neural networks and fuzzy logic, as in general vehicles with a rotating wing are systems with 6 DOF and they are characterised by a high rate of nonlinearity [9, 10, 11, 12].

This paper describes the design of a PI fuzzy controller for controlling the position of a hexacopter. Membership functions and fuzzy controller rules were based on the experience of a pilot (expert) and on analysis of experimental data collected during a pilot-controlled flight, where the pilot´s control commands were sent via joystick into the simulation environment and together with the data from the sensors were saved in the relevant file.

The simulations were carried out in Gazebo robot simulation environment running on a computer with Linux operating system. All algorithms and programmes were written in C++ language and were running in real time.

The objective of the paper has been the application of fuzzy logic principles in the design of a controller for a hexacopter as a nonlinear system. It was our aim

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todemonstrate that even without the knowledge of the structure and the parameters of the system we are able to design a fuzzy controller that has the ability to control the altitude and the position of the hexacopter.

2 Hexacopter Simulation Model

We considered the hexacopter simulation model to be a system with unknown parameters, subsystems and relations between them. The only information available was that about the system´s inputs (Table 1) and outputs (Table 2). Fig. 1 shows the block diagram of the hexacopter system with inputs, outputs and added control structure.

Table 1. System inputs

Input	Description	Units
Throttle	Thrust of the motors	[N]
Roll	Longitudinal tilt of hexacopter	[rad]
Pitch	Lateral tilt of hexacopter	[rad]
Heading	Angular velocity along normal axis	[rad/s]

Table 2. System outputs

Output	Description	Units
X	Position of hexacopter in Earth frame	[m]
Y	Position of hexacopter in Earth frame	[m]
Z	Position of hexacopter in Earth frame	[m]

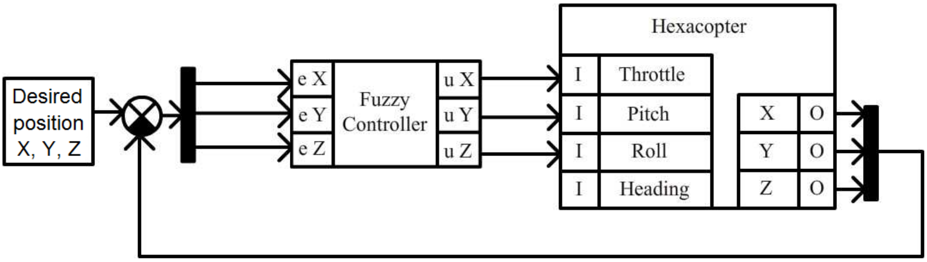

Fig. 1. Block diagram of hexacopter with control structure

The hexacopter 3D model visualization was developed in Gazebo simulation environment (Fig. 2) which is provided with a robust physics engine, with quality graphics and conventional programming and graphic interface. The model runs in real time which enables its direct control by pilot via joystick connected to a PC that enables control of all four inputs. The control data, together with data on position and time were saved in the relevant file and they presented the database needed for the fuzzy controller design.

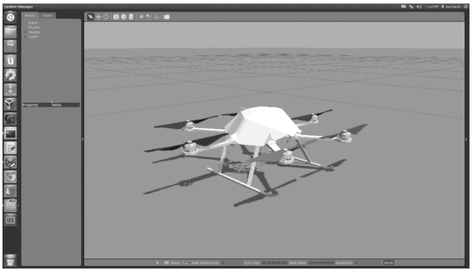

Fig. 2. Model of hexacopter in Gazebo

In order to obtain experimental data several pilot-controlled flights were carried out during which we tried to maintain the hexacopter at a certain predefined altitude. The data collected served for a better understanding of and searching for relations between information on the hexacopter altitude, input throttle value and its dynamic change. The following figures (Fig. 3 to Fig. 5) illustrate experimental data collection results for Z-axis for one pilot-controlled flight.

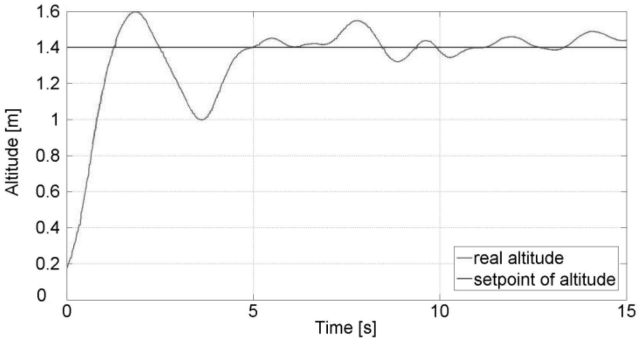

Fig. 3. Real altitude and set point of altitude

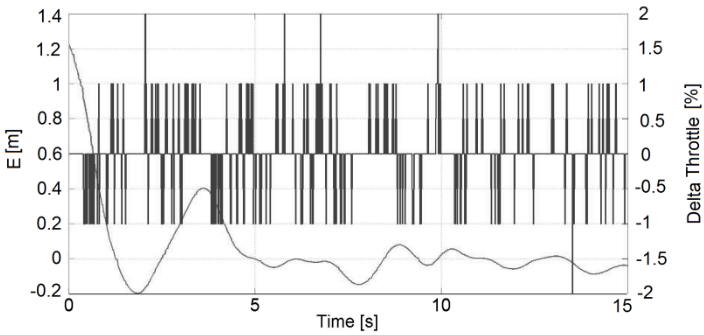

Fig. 4. Real altitude and throttle input

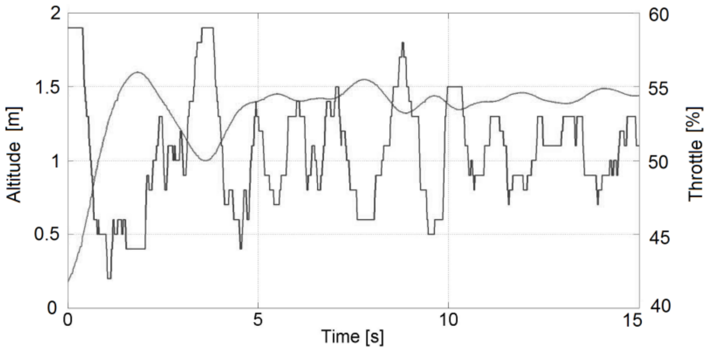

Fig. 5. Altitude deviation and delta throttle input

3 Design of Fuzzy Controller

The objective of the fuzzy controller design was the control of hexacopter position in space, i.e. position control in all three axes X, Y and Z. Hexacopter position control in Z-axis is also described as its altitude control.

A separate discrete fuzzy controller with standard PI structure was designed for position control in each axis [5]. The controller inputs are control deviations between the desired and the real position in the individual axes and their difference, and the output is the gain of the corresponding control action. The resulting fuzzy controller diagram is shown in Fig. 6.

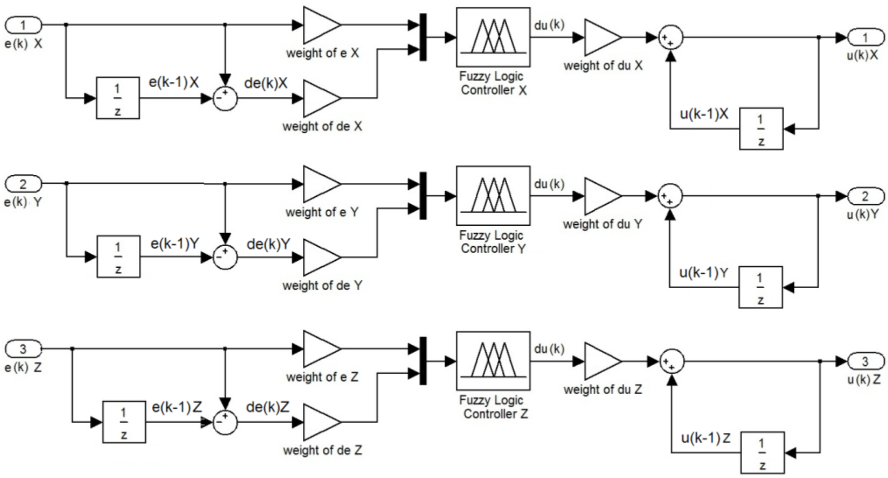

Fig. 6. Internal structure of fuzzy controller

3.1 Design of Fuzzy Controller for Hexacopter Position Control in Z-axis

In the design of hexacopter altitude fuzzy controller (position in Z-axis) we used a standard Mamdani type controller [8], and the fuzzification of variables and proposal of rules were based on the analysis of experimentally measured data and experience of a pilot – expert.

For the sake of simplification, we chose triangular membership function universes of discourse, i.e. each real value of a variable is tuned via scaling universes by means of relevant weight coefficients. On basis of experience from pilot control of flights and analysis of experimentally measured data we proposed a „smoother" distribution of individual membership functions about zero, and a „more rough" distribution for marginal values which represent large deviations and large control actions. The universe of discourse for 2 input and 1 output variable was divided into five levels. (Table 3). The fuzzification of input and output variables is presented in Fig. 7 and Fig. 8.

Table 3. System outputs

Value	Description
Z	**Z**ero
NZL	**N**ear from **Z**ero to the **L**eft
NZR	**N**ear from **Z**ero to the **R**ight
FZL	**F**ar from **Z**ero to the **L**eft
FZR	**F**ar from **Z**ero to the **R**ight

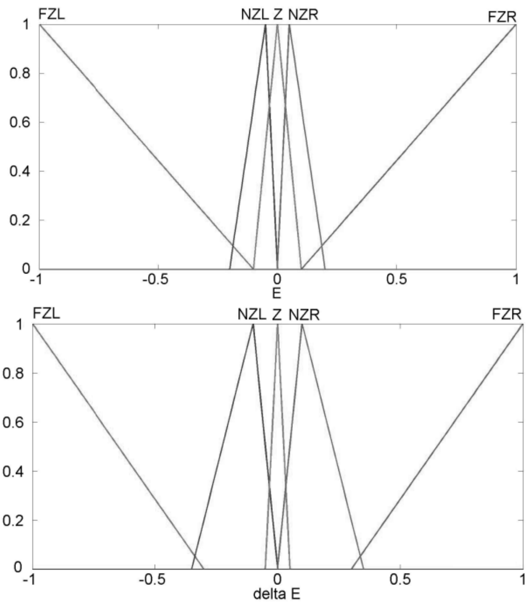

Fig. 7. Membership function of input variables

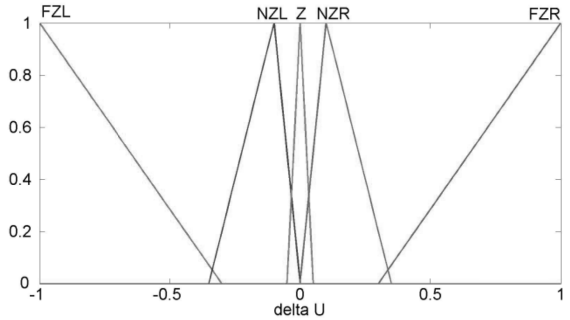

Fig. 8. Membership function of output variable

The main problem in hexacopter altitude control (motor thrust control) is the fact that its propellers are not capable of generating negative thrust. If we want to stop the hexacopter at a certain altitude, we have to apply the brake before reaching this altitude, while the braking is possible only through reducing motor thrust, or stopping the motors. Altitude control as such therefore means balancing between motor thrust force and gravitational force.

The above facts were taken into consideration in the fuzzy controller rules table design (Table 4) which was set up mainly on basis of the pilot-expert´s experience and partially on basis of experimental data analysis.

The resulting hexacopter altitude fuzzy controller is of the Mamdani type and has 25 rules.

Table 4. Rules of relationship among e, delta e and delta u

de/e	**FZL**	**NZL**	**Z**	**NZR**	**FZR**
FZL	FZL	FZL	FZL	FZL	NZL
NZL	FZL	FZL	FZL	NZL	Z
Z	FZL	NZL	Z	NZR	NZR
NZL	NZL	Z	Z	NZR	NZR
FZR	Z	Z	NZR	FZR	FZR

3.2 Design of Fuzzy Controller for Hexacopter Position Control in X- and Y-axis

Contrary to hexacopter altitude control is the control of its position in X- and Y-axis. Position control is based on thrust vector deflection into the direction we want to head the hexacopter. Thrust vector deflection is realised by means of tilting the hexacopter body. This means that if we want to control the hexacopter position we have to control its longitudinal and transverse deflection.

Same as in the design of the hexacopter altitude fuzzy controller, in the design of its position in X- and Y-axes we chose Mamdani type fuzzy controllers with identical fuzzification of input and output variables and with maintaining the triangular form of membership functions. There was a change in the fuzzy controller rules design (Table 5), where the fact that with tilting the hexacopter we can bring about the same deflection into the positive and the negative side was accounted for. For this reason the fuzzy controller rules table shows symmetricity.

The developed fuzzy controllers for hexacopter position control in X- and Y-axes are Mamdani type controllers and they have 25 rules.

Table 5. Rules of relationship among e, delta e and delta u

de/e	FZL	NZL	Z	NZR	FZR
FZL	FZL	FZL	FZL	Z	Z
NZL	FZL	FZL	NZL	Z	NZR
Z	FZL	FZL	Z	NZR	FZR
NZL	NZL	Z	NZR	NZR	FZR
FZR	Z	Z	FZR	FZR	FZR

4 Experimental Results

The properties of the designed fuzzy controller for control of hexacopter position in space were verified by experimental measurements in real time. The fuzzy controller structure was realised in C++ language using the FuzzyLite library. This fuzzy controller communicated with Gazebo robot simulation environment via a predefined communication interface. The Gazebo simulation environment provided information on the hexacopter position (X, Y, and Z) obtained on basis of simulation from visual odometry of the position sensor and sent this information to the fuzzy controller input. From the inputs the fuzzy controller calculated the corresponding control action and sent it back to the simulation environment with 100Hz frequency.

The experimentally measured responses of fuzzy control of hexacopter position in space to step changes of the set-point for the individual axes are shown in Fig. 9 to Fig. 11.

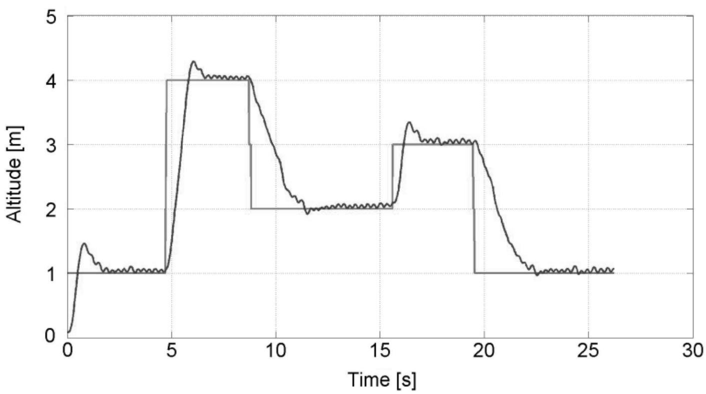

Fig. 9. Altitude (Z) fuzzy controller

In position control in X- and Y-axes floating oscillations about the desired value can be observed. These are caused by the hexacopter moment of inertia during rotation about the relevant axes and by the limited tilt during its rotation.

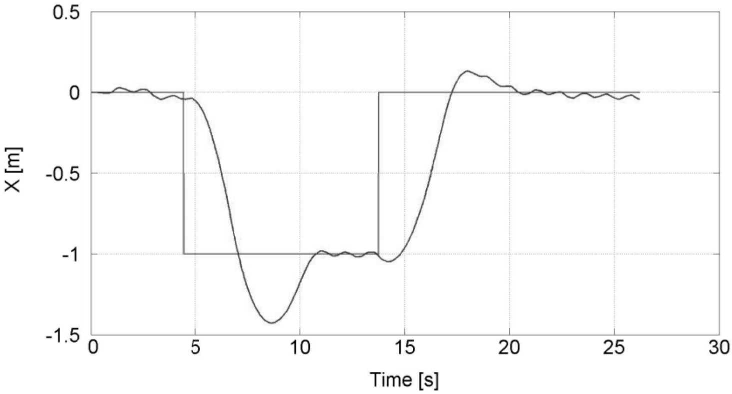

Fig. 10. Position (X) fuzzy controller

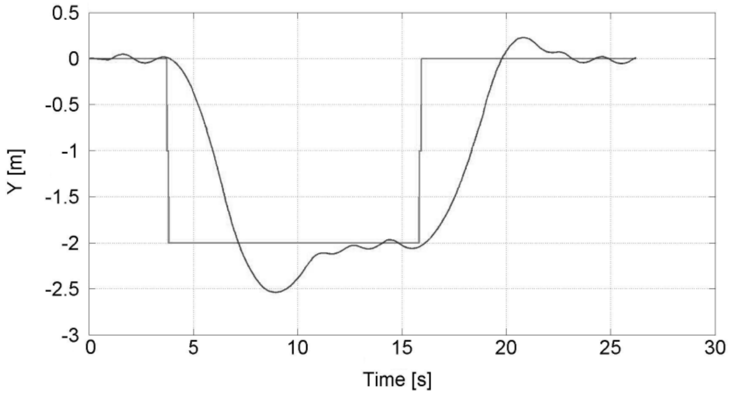

Fig. 11. Position (Y) fuzzy controller

Rules have an important role as they influence the properties of the fuzzy controller. Therefore, in order to try and improve the designed fuzzy controller properties, we also tested other acceptable combinations of rules. As an example we present the case where two Zero values in the last line of Table 4 were replaced by Near Zero Left values. This change influenced the resulting hexacopter altitude fuzzy controller in such a way that during flight of hexacopter upwards there is no overshoot and the hexacopter reaches the desired altitude more slowly and steadily (Fig. 12).

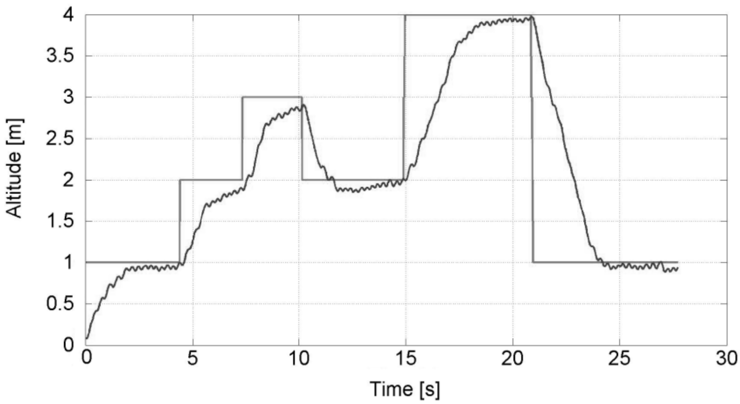

Fig. 12. Behaviour of altitude fuzzy controller with changed rules

5 Conclusion

The paper deals with the design of a fuzzy controller for controlling the position of a hexacopter in space, with absence of knowledge about the structure and parameters of this considerably nonlinear system with 6 degrees of freedom. For the fuzzification of variables and proposal of rules for a Mamdani type controller we used experimental data collected in Gazebo robot simulation environment and also the experience of a pilot – expert. The properties of the controller designed in this way were verified by real time experimental measurements.

The results of experimental measurements have confirmed the rightness of the designed fuzzy controller and have demonstrated its good dynamic properties. The fuzzy controller is capable of holding the hexacopter at the desired altitude and position even at step changes of the desired values. During the hexacopter upward flight the originally designed controller showed a small overshoot which, as it was demonstrated, can be removed, for example, by a minor changing of the rules. Our objective will be to apply the designed controller in the future in a real physical hexacopter model.

The results presented have confirmed the rightness of fuzzy systems deployment in the control of unmanned aerial vehicles. However, it is not always possible to obtain the expert knowledge required for fuzzy controller design, or to use universal „meta rules“, especially in the case of nonlinear high order systems. For this reason, research efforts concerning fuzzy logic control in unmanned aerial vehicles in the following years should be devoted to systematic analysis and design of fuzzy control systems that do not demand heuristic searching for linguistic control rules. This most often involves methods based on fuzzy models of the controlled systems.

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References

1. Norgaard, M., Ravn, O., Pulsen, N.K., Hansen, L.K.: Neural Networks for Modelling and Control of Dynamic Systems. Springer, London (2000)
2. Stojcsics, D.: Fuzzy Controller for Small Size Unmanned Aerial Vehicles. In: IEEE 10th International Symposium on Applied Machine Intelligence and Informatics (SAMI), Slovakia, pp. 91–95 (2012)
3. Bickraj, K., Pamphile, T., Yenilmez, A., Li, M., Tansel, I.N.: Fuzzy Logic Based Integrated Controller for Unmanned Aerial Vehicles. In: Florida Conference on Recent Advances in Robotics, FCRAR (2006)
4. Kurnaz, S., Çetin, O.: Autonomous Navigation and Landing Tasks for Fixed Wing Small Unmanned Aerial Vehicles. Acta Polytechnica Hungarica 7(1), 87–102 (2010)
5. Shengyi, Y., Kunqin, L., Jiao, S.: Optimal tuning method of PID controller based on gain margin and phase margin. In: International Conference on Computational Intelligence and Security, pp. 634–638 (2009)
6. Beard, R.: Autonomous Vehicle Technologies for Small Fixed-Wing UAVs. Journal of Aerospace Computing Information and Communication 2(1), 92–108 (2005)
7. Korba, P., Pila, J.: Aplikácia CAx systémov pri projektovaní konštrukčných uzlov vrtuľníka. Zaklad Poligraficzny, Wisla (2007)
8. Zilkova, J., Timko, J.: A Fuzzy vector control of asynchronous motor. Acta Technica 55(3), 259–274 (2010)
9. Sastry, S.: Nonlinear Systems: Analysis, Stability, and Control. Springer, New York (2010)
10. Modrlak, O.: Fuzzy řízení a regulace. Technická univerzia v Liberci, Liberec (2004)
11. Wicaksono, H., Christophorus, B.: T1-Fuzzy vs T2-Fuzzy Stabilize Quadrotor Hover with Payload Position Disturbance. International Journal of Applied Engineering Research 9(22), 15251–15262 (2014)
12. Chao, H., Luo, Y., Di, L., Chen, Y.: Fractional order flight control of a small fixed-wing UAV: Controller design and simulation study. In: Proceedings of the ASME 2009 International Design Engineering, Technical Conferences & Computers and Information in Engineering Conference, pp. 621–628 (2009)