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Designing and Simulation for Vertical Moving Control of UAV System using PID, LQR and Fuzzy logic

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ABSTRACT

This paper presents the designing and simulation for vertical moving control of Unmanned Air Vehicles (UAV) system using Proportional Integral Derivative (PID) control method, Linear Quadratic Regulator (LQR) control method and fuzzy logic control technique.The UAV system pose a challenger control problem that in it precise model of system is non-linear. The conventional PID controller, the LQR controller, Fuzzy Logic Controller (FLC) and Self-Tuning Fuzzy PID controller are designned based on the dynamic modeling of the system is derived from a suitable mathematical model to describe the vertical motion of a UAV. Simulation results in Matlab and Simulink show that by using self-tuning Fuzzy PID, the performance of vertical moving control system is improved significantly compared to Other controllers.

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1. INTRODUCTION

Nowdays an aircraft with high performance relies heavily on automatic control system for monitor and control many of aircraft subsystems. In this regard, engineers have tried to design the guidance and control system, such as variable structure control, self-adaptive control, compound control and so on [6], [7], [8]. UAV is an aircraft without manned, that may be remotely controlled or self-controlled by onboard computers. There are a wide variety of drone with different shapes, sizes, configurations, and characteristics. Often countries have taken the development of UAV as priority. UAV is mainly used for military applications, but is applied in growing number of civil applications, such as policing, fire-fighting.Generaly for missions that are too "*dull, dirty,or dangerous*" UAVs are preferred than to manned aircrafts. The modern UAV should have abilities of wide airspace flight and precise flight that the automatic control system based on intelligent computational techniques such as artificial neural network (ANN), fuzzy logic theory (FL), genetic algorithm (GA) and etc, which have given novel solutions to the Flight Control system problems.

The term "*fuzzy logic*" was introduced with the 1965 proposal of fuzzy set theory by Lotfi A. Zadeh [21]. The pioneering research of mamdani and his colleagues on fuzzy control [14], [15], [16] was motivated by zadeh's seminal papers on the linguistic approach and system based on the theory of fuzzy sets [17], [18], [19], [20]. Fuzzy logic used in many fields, for sample control theory to artificial intelligence. Fuzzy logic control is an intelligent control method based on language rules. The core of fuzzy control algorithm is fuzzy inference that is an algorithm with the ability of human thinking. FLC is the representative one among many intelligent control methods which has already achieved many successful applications in industry field including in the vertical moving control and it is convenient to implement in the complex process [2], [3], [12], [13].

PID control has prominent advantages and it is widely used as an effective control scheme such as simple controller structure and easier parameter adjusting. The Although conventional PID control works well on linear system only near the design point but when object system goes far away from the design point it’s hard to hold dynamic performance. The Self-tuning fuzzy PID controller is based on the conventional PID controller that has advantages both fuzzy control and PID control [10]. The paper aims to studying the vertical moving regulation of UAV under the step input.To solve this problem, theories of PID control, LQR control, fuzzy control and self-tuning fuzzy PID are analyzed to demonstrate the effectiveness of the control schemes, the comparative assessment on the system performance for each of controllers are presented then they are designed. Finally, Simulation is developed within Simulink and Matlab for evaluation of the control strategies.

2. UAV SYSTEM

UAV is a multi-input and multi-output nonlinear system. To maintain neat formation, it is necessary to precisely control the formation of each of UAVs in flight. The relative distance between the wing planes and the lead planes is most important thing of UAV formation (forward, lateral and vertical). The plane movement equations can be divided to independent equations of forward, vertical and lateral movement for discuss. In order to facilitate system analysis and space limitations control in this paper only the vertical angle control has been considered that has controlled by the steering [4]. The schematic picture of the UAV system is given in Figure 1.

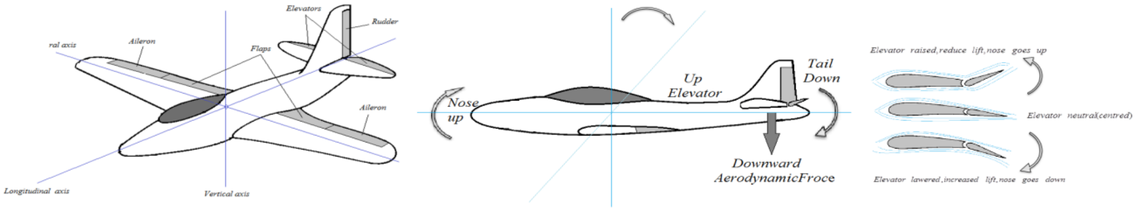


Figure 1. The UAV body coordinate system and Elevator position

2.1. Case study: Vertical Moving Control

The Vertical linearized equation of flight control system is represented in a state-space form [4] according to the aerodynamic parameters as follow:

$$\begin{bmatrix} \Delta\dot{v} \\ \Delta\dot{a} \\ \Delta\dot{w} \\ \Delta\dot{\vartheta} \end{bmatrix} = \begin{bmatrix} -0.045 & 0.183 & 0 & -0.241 \\ -0.312 & -1.945 & 1 & 0 \\ 0.152 & -22.511 & -2.036 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \Delta v \\ \Delta a \\ \Delta w \\ \Delta\vartheta \end{bmatrix} + \begin{bmatrix} -0.007 \\ 0.124 \\ -17.105 \\ 0 \end{bmatrix} \Delta\delta \tag{1}$$

Where ΔV , a, W_X , ϑ and δ_z are percentage velocity of increment(m/s), angle of attack(rad) ,pitch rate(rad/s), pitch angle(rad) and elevator deflection angle(rad).Vertical movement is divided into short-period mode and long-period mode.The initial period response takes attack angle and angular velocity as the representative of the short-periodic motion. Flight speed is essentially the same. If $V = 0$ the Vertical movement is simplified and the freedom short-period model is as follow:

$$\begin{bmatrix} \Delta\dot{a} \\ \Delta\dot{w}_z \end{bmatrix} = \begin{bmatrix} -1.945 & 1 \\ -22.511 & -2.036 \end{bmatrix} \begin{bmatrix} \Delta a \\ \Delta w_z \end{bmatrix} + \begin{bmatrix} 0.124 \\ -17.105 \end{bmatrix} \Delta\delta_z \tag{2}$$

This simplified equation can be used to calculate the transfer function from steering gear to the pitch rate as shown in equation (3)

$$\frac{\vartheta(s)}{\delta(s)} = \frac{-17.11S - 36.06}{S^2 + 3.981S + 26.47} \tag{3}$$

By using a steering inertia model transfer function is:

$$\frac{\delta(s)}{\nu(s)}=\frac{Ka}{\tau.S+1} \tag{4}$$

Where ν, Ka, and τ are the input voltage, elevator serve gain and servomotor time constant respectively. For typical servomotors time constant falls down to a range (0.05, 0.25) sec. In this design, assume time constant is 0.1 sec and ka is -1. This pitch angle rate can be drawn with open-loop system Transfer function:

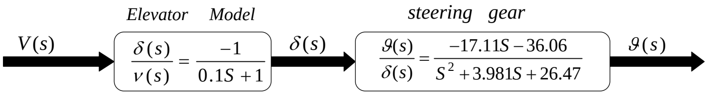


Figure 2. Vertical Moving control Diagram

Finally the transfer function is given by:

$$G(s)=\frac{\vartheta(s)}{\nu(s)}=\frac{171.1S+360.6}{S^3+13.981S^2+66.28S+264.7} \tag{5}$$

The result state matrix after performance in MATLA is as following:

$$A=\begin{bmatrix}-13.981 & -8.285 & -4.1359\\ 8 & 0 & 0\\ 0 & 8 & 0\end{bmatrix},\quad B=\begin{bmatrix}4\\0\\0\end{bmatrix},\quad C=\begin{bmatrix}0 & 5.3469 & 1.4086\end{bmatrix},\quad D=0 \tag{6}$$

2.2. Stability

To investigate the stability of this system the Nyquist method [11] is applied and the result is presented in Figure 3. Although the system is stable, its response to the input step shows: oscillations, long settling time, high overshoot and high steady-state error (Figure 3).

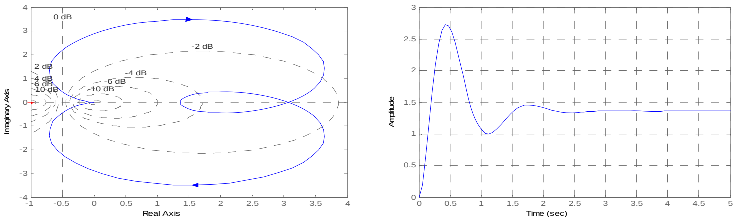


Figure 3. The Vertical Moving Nyquist plot and Step Response

3. RESEARCH METHOD

In this section, four control schemes are proposed and described with detail: PID controller, LQR, FLC, and Self-tuning Fuzzy PID. Here, four considerations have to be met so that settling time from less than 2 s to less than 5 s, percentage of overshoot to less than 5% and steady state error to less than 2% would be reduced.

3.1. PID Controller

A PID controller is a generic control loop feedback mechanism and regarded as the standard control structures of the classical control theory. PID is the most commonly used feedback controller, literally everywhere in industrial applications. The controller attempts to minimize the process error by continually adjusting the inputs [22]. The equations of PID control are given as following:

$$u(t) = K_P e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \quad or \quad u(t) = K_P \left(e(t) + \frac{1}{T_i} \int_0^t e(\tau)d\tau + T_d \frac{de(t)}{dt} \right) \tag{7}$$

This paper obtained the value of PID gains by Ziegler and Nichols method [22] are set to Kp=10, Ki=2.5 and Kd=3.

3.2. LQR Controller

Recently modern control theory has made a significant impact on the aircraft industry [9]. LQR is an optimal control approach which is based on closed loop optimal control with the linear state feedback or output feedback [1] .The simulated block diagrams of state feedback controller displayed in Figure.4

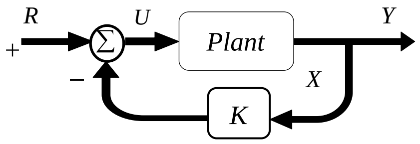


Figure 4. Block Diagram of LQR Controller

In LQR, a cost function is minimized to provide the best control signal.

$$J = \int_0^\infty (x^T Qx + u^T Ru)dt = \int_0^\infty x^T Qxdt + \int_0^\infty u^T Rudt \tag{8}$$

The selection weight matrices Q and R are very importance in LQR that should be symmetric and nonnegative matrices. The weight matrices affect the control performance. These matrices are determined by experience of engineers who are familiar with the controlled system [1]. Determination the matrix K of the optimal control, $u = -KX$, is written as:

$$K = R^{-1} B^T P \tag{9}$$

And P is defined by solving the algebraic Riccati equation (ARE)

$$A^T P + PA - PBR^{-1} B^T P + Q = 0 \tag{10}$$

Finding the gain vector, K, is goal of controller design. Controller can be tuned by changing the nonzero elements in q matrix which are following as:

$$\mathrm{R} = 1; \mathrm{Q} = [\mathrm{X}_1\ 0\ 0 ; 0\ \ \mathrm{X}_2\ \ 0 ; 0\ 0\ \mathrm{X}_3] \tag{11}$$

Consequently, by tuning the values of $X_1 = 3.8$, $X_2 = 32.14$ and $X_3 = 0.922$, the following values of matrix K are obtained.

$$K = [2.4054\ \ 4.7004\ \ \ 0.3771] \tag{12}$$

3.3. Fuzzy Logic Controller

FLC is a fast developed technology over the last decade. In this study, FLC has been applied for stabilization of the Vertical Moving control system. FLC is conceived as a better method for sorting and handling data. Also it has proven to can be an excellent choice for many control system applications because of non-linearity, complex mathematical computation and real-time computation needing. Generally, a fuzzy control system consists of four basic segments: fuzzy processing, fuzzy rule base, fuzzy inference and de-fuzzy processing. A conceptual presentation of the FLC in a closed-loop system is shown in Figure 5. In the FLC method, there exist two inputs and an output. The inputs are the error, E(t), and the error gradient, Ec=dE(t)/dt. The input signals, the error and derivation of error are converted to fuzzy parameters. The most frequent approach of fuzzy inference system, Mamdani model, is applied for inferring. The fuzzy inference block is shown in Figure 5.

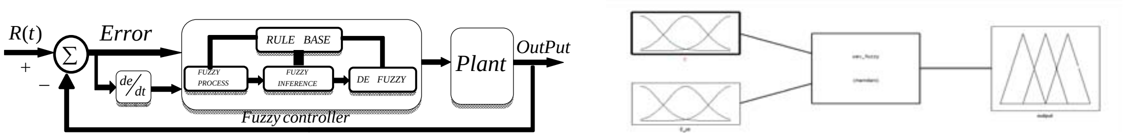


Figure 5. The FLC for the Vertical Moving Control System and Fuzzy Inference Block

At first, the input variables need to be converted from exact quantities into fuzzy quantities that it should be the infrastructure for fuzzy inference. This process may be considered as a mapping from accurate quantities to fuzzy subsets by the membership functions. For achieve a practical range, the controller is simulated with the model with different parameter quantities. The changes of membership functions are defined based on the influence on the control performance. All of the fuzzy subsets of the outputs and the inputs of the fuzzy controller are represented by triangular membership functions. The fuzzy sets for input variables and output consisting of seven linguistic variables such as, Positive Big, Positive Middle, Positive Small, Zero, Negative Small, Negative Middle, and Negative Big or {NB,NM,NS,Z,PS,PM,PB}. For sample membership functions of inputs E and Ec are shown in Figure 6.

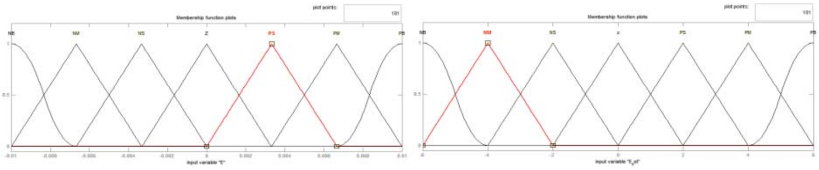


Figure 6. Membership functions of the linguistic variables for E, Ec, and output.

The inputs are the classical error, E(t), and the rate of the change of error (dE(t)/dt). The fuzzy rules based on empirical knowledge of expert are shown in Table 1.

Table 1. FLC Rule Based

E Ec	NB	NM	NS	Z	PS	PM	PB
NB	Z	PS	PM	PB	PB	PB	PB
NM	NS	Z	PS	PM	PB	PB	PB
NS	NM	NS	Z	PS	NM	NM	NM
Z	NB	NM	NS	Z	PM	PM	PM
PS	NB	NB	NM	NS	Z	PS	PM
PM	NB	NB	NB	NM	NS	Z	PS
PB	NB	NB	NB	NB	NM	NS	Z

3.4. Self-Tuning Fuzzy PID Controller

The new PID control strategies based on some intelligent algorithms [5] can improve dynamic performance far away from the design point. The Self-tuning fuzzy PID controller is base on the conventional PID controller that employs the Fuzzy Inference System (FIS) to tune the PID parameters that has both advantages fuzzy control and PID control. In the Self-tuning fuzzy PID, there exist three outputs and two inputs. The outputs are PID coefficients, Kp, Ki and Kd. The inputs are the error, E(t), and the error gradient, Ec=dE(t)/dt.In the fuzzy self-tuning of the input signals, the error and derivation of error are converted to fuzzy parameters. Then, fuzzy inference provides a nonlinear mapping from the inputs to the PID coefficients.The Self-tuning fuzzy PID in a closed-loop system is shown in Figure 7. The configuration of the implemented Self-tuning fuzzy PID in this study is presented in Figure 7.

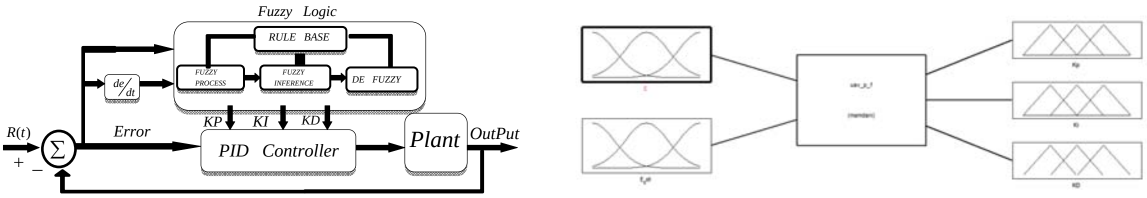


Figure 7. Structure of the Self-Tuning Fuzzy PID Controller and Fuzzy Inference Block

The membership functions of inputs e and ec are shown in Figure 8.

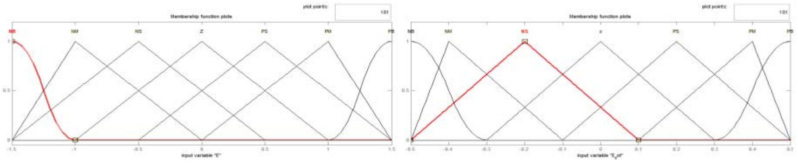


Figure 8. Membership functions of the linguistic variables for E, Ec

The membership functions of outputs Kp, Ki and Kd are shown in Figure 11. The linguistic variables of these outputs are assigned as: Kp=Ki=Kd={NB,NM,NS,Z,PS,PM,PB}.

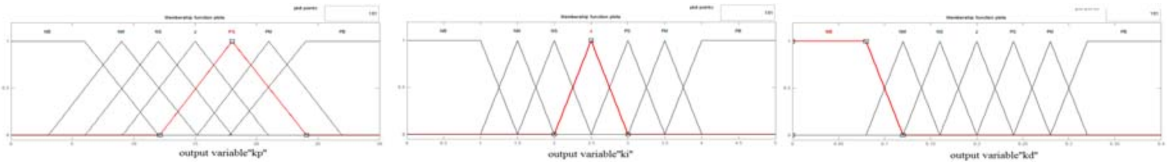


Figure 9. Membership functions of the linguistic variables for Kp, Ki and Kd

Generally, fuzzy rules are depended to the plane that be controlled and the summary of designer's knowledge and experience. Therefore the fuzzy rules are formulated as they are presented in Table 2.

Rule 1: If E(t) iS NB and Ec (t) is NB then Kp = PB and Ki = NB and Kd = PB.

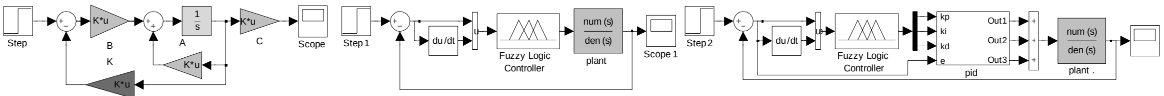
Table 2. Fuzzy Rules of Kp, Ki and Kd

Ec	E Kp-Ki-Kd	NB	NM	NS	Z	PS	PM	PB
	NB	PB-NB-PB	PB-NB-PB	PB-NB-PB	PM-NM-PM	PS-NM-PS	Z-Z-Z	Z-Z-Z
	NM	PB-NB-PB	PB-NB-PB	PM-NM-PM	PM-NM-PM	PS-NS-PS	Z-Z-Z	Z-Z-Z
	NS	PB-NB-PM	PM-NM-PM	PM-NM-PM	PS-NS-PS	Z-Z-Z	NS-PS-NS	NM-PM-NS
	Z	PM-NM-PM	PM-NM-PM	PS-NS-PS	Z-Z-Z	NS-PS-Z	NM-PM-Z	NM-PM-Z
	PS	PM-NM-PM	PS-NS-PS	Z-Z-Z	NS-PS-NS	NM-PM-NS	NM-PM-NM	NB-PB-NM
	PM	Z-Z-Z	Z-Z-Z	NS-PS-NS	NM-PM-NS	NM-PM-NM	NB-PB-NB	NB-PB-NB
	PB	Z-Z-Z	Z-Z-Z	NM-PM-NS	NM-PM-NS	NB-PB-NM	NB-PB-NM	NB-PB-NB

4. SIMULATION AND RESULT ANALYSIS

4.1. Implementation and Results

In this section, the proposed of control schemes are implemented and the corresponding results are presented. A unit step command is required in order for vertical moving to follow the reference value. The simulation block diagram designed for the vertical moving UAV system is shown in Figure 10. In the diagram, the LQR, FLC and the proposed self-tuning fuzzy PID controller are modeled and simulated in Simulink.



LQR Fuzzy Logic Controller Self-Tuning PID Fuzzy

Figure 10. Simulink Models of LQR, FLC and fuzzy self-tuning PID controller

The simulation results for the closed loop system response under conventional PID, LQR, FLC, and self-tuning fuzzy PID controller are shown in Figure 11. The results demonstrate that LQR controller has the fastest response with the settling time of 0.3 s and rising time of 0.195s. For the percent of overshoot, LQR has 1.1% which is met the desired requirement of controller design and produce steady state error (Ess) is 0.02%.

PID controller and FLC provides acceptable performance in term, both of them have nearly fast response regarding to the settling time and rise time. Their percent Overshoot are 0.09% and 0.33% respectively. The results also demonstrated that PID controller is without steady-state error and the artificial fuzzy logic controller reduces steady-state error up to 0.0013%.

In the Self-Tuning Fuzzy PID controller, the parameter's value of Kp, Ki and Kd are tuned by using signals from fuzzy logic block based on the change of error between reference signals and output signals. This controller is able to give a perfect response without produce any overshoot and any steady state error. The response is comparatively fast that give the settling time about 0.4381 s and rise time about 0.2653 s.

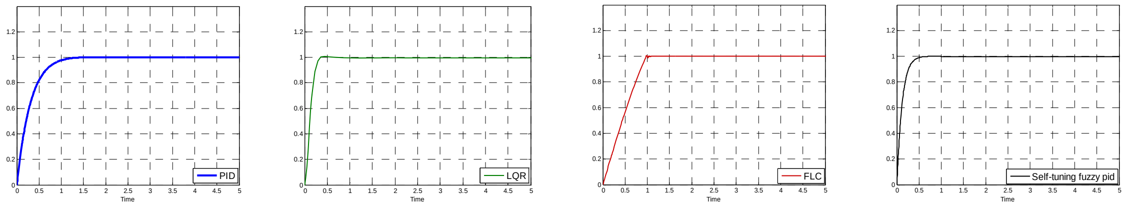


Figure 11. The Vertical Moving Response with All Controllers

4.2. Comparison and Discussion

The output response and the dynamic parameters of four control schemes with respect to the step reference input signal are shown in figure 12.

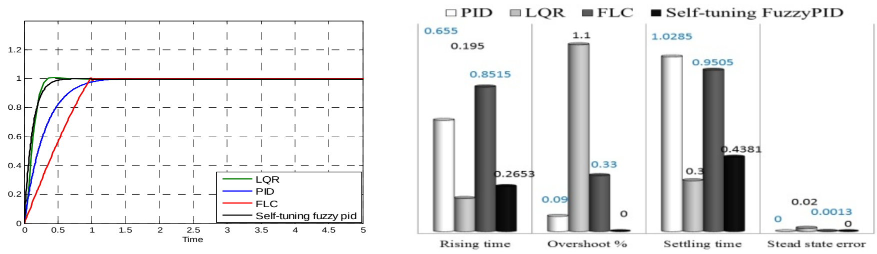


Figure 12. Performance comparison controllers

From the figure 12, it can be seen that self-tuning fuzzy PID controller has the best performance and has achieved better response in compare other controllers. It indicates faster settling time and faster rising time. At the same time, four control designs produce the output response without steady-state error and without overshoot. Therefore, from the obtained results in Figure 12, it can be concluded that performance of Vertical Moving control system using self-tuning fuzzy PID controller has been improved.

5. CONCLUSION

In this work, the transfer function of a UAV system is extracted then its stability is investigated. In order to improve the response parameters such as oscillation, rise time, overshoot, settling time and steady state error less, Four control design proposed has been implemented within simulation environment in Matlab and Simulink. Based on the Simulation results, the system responses indicate the performance Vertical Moving Control System has improved significantly using self-tuning fuzzy PID than other controllers. In order further research, effort can be devoted in developing more robustness control techniques, following by adopt the control scheme in practical application.

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