A Comparative Study of PID Control for VTOL based UAV System

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ABSTRACT: Unmanned aerial vehicles (UAVs) due to their hovering and vertical take-off and landing, have acquired a lot of interest from researchers. In order to implement UAVs, different techniques and methods are used. QNET VTOL 2.0 board in the field of unmanned aerial vehicles is an important platform designed for NI ELVIS II. In this research a comparative study of PID tunning for QNET VTOL 2.0 board, using LabVIEW is presented. Three tuning methods heuristic(error and trial) method, intelligent tunning using fuzzy logic and ANFIS(adaptive neuro fuzzy inference system) are chosen for comparison on the basis of literature. The proposed PID tunning methods are applied to the existing PID controller for controlling the pitch angle of QNET VTOL 2.0 board. The main purpose of this study is to compare the performance of proposed three tuning methods on the basis of step characteristic (rise time settling time , peak time and maximum overshoot). From the experimental results it is found that implementation of ANFIS has improved the simulation results significantly as compare to the self-tuned fuzzy PID and conventional PID.

Keywords: UAV, PID, FUZZY LOGIC, ANFIS, VTOL.

1. INTRODUCTION

UAV(Unmanned Ariel vehicle) is an autonomous aircraft that can move autonomously and remotely controlled by a user. They have been broadly utilized in number of civilian applications e.g., Target tracking [1], Wildlife protection [2], Orchard monitoring [3], Infrastructure inspection [4], Disaster rescue [5]. It has become the preferred platform for research and development of the flight autonomous control systems. The QNET VTOL 2.0 is a board which introduces vertical take-off and landing (VTOL). The VTOL is an autonomous aircraft that can hover, take off and land vertically. The board is specifically accomplished for NI ELVIS II and programmed in LABVIEW environment. The existing controller in QNET VTOL 2.0 is PID controller [6]. Because of its simplicity and robustness, a PID controller is widely utilized in industrial control actions. The three main control effects of PID controller are proportional, integral, and derivative control. For desired closed loop specifications, the tuning of PID controller is carried out. There are various methods used to tune the PID controller. This research focuses on three tuning methods, first one method applied to tune the gain parameters of PID is Heuristic (Error and trail) method, In this method first of all the derivative and integrals terms are brought to zero and proportional term is increased constantly. To keep the oscillations on a constant rate the proportional term is increased. Once the constant rate is achieved the proportional is stopped increasing and the stability of system should not be disturbed. When the stability in proportional response is achieved then integral value is changed until steady state error becomes negligible. The overshoot might increase in return. When the proportional and integral values have been set, with negligible steady state error then increase the derivative value to a point where it responds quickly to the set point. Thus, the overshoot of controller response is decreased [1]. After error and trail experience PID is **intelligently** tunned using fuzzy logic, it is an approach which mimics the human intelligence. Instead of True/False (as in binary system) it uses the Degree of truth approach. In traditional/binary logic there are only two possibilities either true or false (1 or 0) but in fuzzy logic there is degree of truth, it has multiple possibilities between 0 and 1[2][3]. Another method applied for PID tuning in this research is Adaptive Neuro Fuzzy Inference System (ANFIS), it is the combination of artificial neural networks and fuzzy logic. ANFIS tries to incorporate human thoughts to solve problems without mathematically modeling them, using learning process that includes learning algorithm and requires data for training. ANFIS is initially trained, once it gets trained testing of trained data is carried out then applied to the controller.

This research demonstrates the comparative study of all the three tuning methods mentioned earlier, to observe the response of all methods and to suggest which one method is best for PID tunning in QNET VTOL board.

2. LITERRATURE REVIEW

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A number of research papers have been written to demonstrate the comparison of PID tunning methods Several researchers have implemented the self-tunned fuzzy PID and ANFIS for PID tunning to control the pitch of VTOL aircrafts. A brief review of related work is given as follows.

Junejo, et al. [7] studied the properties of the QNET VTOL 2.0 model, and simulated the LabVIEW pitch angle control model, and developed an intelligently tuned PID controller for QNET VTOL 2.0 model to control the pitch angle using Fuzzy logic, and compared the results with the current PID controller. They introduced the fuzzy block in the plant model which accepts error and derivative of error as inputs and provided the tunned proportional integral and derivative gain values to the existing controller. They compared the response of auto tunned PID controller to the conventional PID controller based on step characteristics where autotuned PID provided better response than conventional PID.

Morocho-Caiza, et al. [8] presented a comparison of the regularity of the vertical take-off and landing (VTOL) plant behavior among a traditional PID controller and a neuro-fuzzy PID controller. The stabilization period of the plant was measured, over several step test, which was decreased in approximately 30 s using neuro-fuzzy controller. Moreover, with the fuzzy PID compared to the classic PID controller, the integral square-error of the plant response was decreased. Simulation was carried out in MATLAB Simulink.

Abasi, [9] Developed an adaptive fuzzy controller to tune the conventional PID controller and controlled the altitude of quadrotor VTOL vehicle. The performance of the controllers was checked, evaluated and compared using MATLAB Simulink., several test were done and then applied to real quadrotor.

Sarhan, et al. [10] demonstrated An adaptive PID flight controller based on the optimization parameter fuzzy inference for controlling the altitude dynamics of the Aerosonde UAV,. To tune the PID parameters, the online fuzzy inference is introduced as a self-adaptive method. Compared to the fuzzy-based controller and genetically tuned control, Improvement has been demonstrated by the performance of the adaptive PID flight controller.

Fernandes, et al. [11] presented A comparative study of regulation of Altitude and Yaw control for Rotor craft UAV. They compared control strategies based on PID, LQR and Lyapunov to control the altitude and yaw and analyzed the performance in terms of response time. The performance analysis of all three proposed methods is carried out in MATLAB. They did not control the pitch of rotorcraft.

Wahid, et.al, [12] Compared conventional PID controller with self-tuning fuzzy PID based on time response for an autopilot of longitudinal dynamics in pitch aircraft. The controller is designed to assess the longitudinal motion of the aircraft based on dynamic modeling with a derivation of the mathematical device model. They worked on a simulation-based model and concluded that the efficiency of the pitch control system improved significantly compared to the traditional PID by implementing self-tuning fuzzy PID.

Khalid, et al.[13] presented design and analysis of an aircraft for pitch control. To control pitch of an aircraft, traditional PID, Sliding Mode (SM) and Fuzzy PID controllers have been developed and evaluated. In MATLAB Simulink, simulations are carried out for the suggested controllers and the results are examined on the basis of different performance measures. In order to compare the results of the controllers, Integral Absolute Error (IAE), Integral Squared Error (ISE), under shoot, settling time and rise time are taken in consideration. Simulation results, in addition to comparison, authenticates the robustness and improved performance of Fuzzy PID and SMC of an aircraft to control the pitch angle.

It can be observed from the literature review that most of the comparative study on tuning the PID control has been done on the basis of simulation. Since UAVs are governed in a nonlinear fashion, the implementation of auto tuned PID control should be performed better than the conventional PID. The recent study shows that when compared to a conventional PID controller, the fuzzy-PID and ANFIS based PID controller provides promising results. The fuzzy-based PID tuning method for altitude and pitch angle control was addressed in the majority of the literature review because of their significance. To prove such hypothesis, a proper comparative study is required in real time. This study proposed a comparison of conventional PID, fuzzy-based PID and ANFIS-based PID tuning methods for real-time pitch angle stabilization.

PID CONTROLLER

PID controller is the most extensively used controller because of its simple structure, good performance for several processes and can be tuned even without a particular model of the controlled system. A proportional–integral–derivative (PID) controller is a control loop feedback mechanism and frequently measures an error value as the difference between a desired fixed point and a measured variable [7]. Eq.(1) Shows the system's closed-loop transfer function, from the reference r position to the angular VTOL position output θ, whereas Eq.(2) (3) (4) shows the three parameters for the implementation of PID controller that are proportional gain (Kp), integral gain (Ki), derivative gain (Kd), are computed from transfer function of QNET VTOL 2.0.

$$G_{\theta,r}(s)=\frac{K_t(K_p+K_{i})}{Js^3+(B+K_tK_{d})s^2+(K+K_tK_p)s+K_tK_i} \quad (1)$$

$$K_p=\frac{-K+2\,p_o\zeta\omega_nJ+\omega_n{}^2J}{K_t} \quad (2)$$

$$K_i=\frac{p_o\omega_n{}^2J}{K_t} \quad (3)$$

$$K_d=\frac{-\beta+p_oJ+2\,\zeta\omega_nJ}{K_t} \quad (4)$$

3. METHODOLOGY:

In this section three PID tunning methods are proposed and described in detail i.e. heuristic (error and trail) method, auto tunning via fuzzy and ANFIS, to control the pitch angle angel of QNET VTOL 2.0 board. The proposed PID tunning methods were implemented on the existing PID control of QNET VTOL 2.0 model. The simulation results achieved by applying all three tuning methods, compared in terms of step characteristic i.e. rise time, settling time, peak time and maximum overshoot. Fig.1 shows the block diagram of proposed methodology

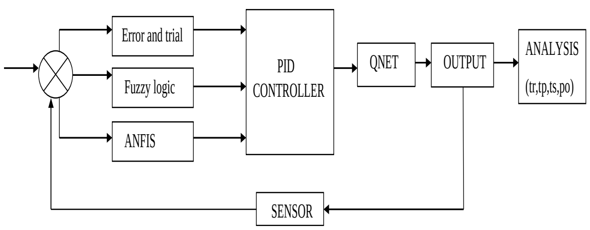

Fig (1) block diagram of proposed methods for tuning PID controller of QNET VTOL 2.0

3.1. PID TUNING METHODS

3.1.1 HEURISTIC (ERROR AND TRIAL) METHOD

One of the tuning methods used to tune the PID controller is the error and trial method. It is a manual method, value of the gains Kp, Ki and Kd are inserted manually. The gain values depend on the system. Different values of the gains are inserted manually to obtain the desired output according to the system requirement. In error and trial method initially Each coefficient of PID controller is brought to zero. Then the proportional gain is increased until the control loop output starts to oscillates at a constant rate.. Once the proportional response became stable, the integral term is increased to reduce the oscillations gradually. Keep changing the integral value until the steady state error gets reduced, which could increase the overshoot. Once proportional and integral parameters have been adjusted with minimal steady state error to the desired values. Increase the derivative gain as far as the system reacts to get stable to its set point. With help of error and trial method better response can be achieved by changing the gains Kp, Ki and Kd such as:

Kp is used to minimize the rise time

Kd is used for the reduction of overshoots and settling time

Ki is used for elimination of steady state error

Initially, the gain values were selected as Kp = 0.0747, Ki = 0.3588 and Kd = 0.1409 on the basis of error and trail experience, since the system response obtained was not too good so on the basis of error and trail another set of gain values was chosen as Kp = 0.1, Ki = 0.4 and Kd = 0.2. Simulation results for both set of values is shown and discussed in result and discussion section.

3.1.2 FUZZY LOGIC

Fuzzy logic is an approach which mimics the human intelligence, instead of True/False or 0/1 (as in binary system) it uses the Degree of truth approach, it has multiple possibilities between 0 and 1. Fuzzy logic is a method used to tune the gain parameters of PID controller.

With the help of literature review [12] a fuzzy logic rule base is generated which takes error and derivative of error as inputs and gives Kp Ki and Kd as outputs of fuzzy controller. For each input and output seven membership functions are assigned which are identical but the width of each input and output chosen is different. The span of fuzzy sets is determined by experience of error and trial and is selected as:

- e =[-0.4 0.4]
- ed =[-4 4]
- Kp=[-0.0012 0.2012]
- Ki=[0.2352 0.5648]
- Kd=[-0.0364 0.4364]

A set of forty-nine rules is defined on the basis of seven membership functions of error and seven membership functions of derivative of error. With the help of these rules the gain values Kp Ki and Kd are tuned and applied to the existing PID controller of QNET VTOL 2.0 plant. The response achieved by fuzzy tuned PID controller is shown and discussed in results and discussion section.

3.1.3 ANFIS (Adaptive Neuro Fuzzy Inference System)

ANFIS is the combination of neural network and fuzzy inference system known as Adaptive neuro fuzzy inference system. Both the neural network and fuzzy logic are taken into consideration.

Artificial Neural Network (ANN) is a collection of neurons in a particular arrangement that can compute or estimate any function and stores the knowledge in memory as experience for future use. The stored knowledge is known as numeric data which is transferred between neurons through weights. The weights are associated with the output of each individual neuron also known as inter neuron connection strengths in adjacent layers. ANN learns through training, based on training the weights associated with each neuron adjust themselves.

In this research gain values of PID controller Kp Ki and Kd are tuned by introducing ANFIS which is trained with the help of data set obtained from fuzzy PID. As ANFIS combines both neural network and fuzzy, so FIS(fuzzy inference system) is designed with respect to the neural network, which consist of five layers. The data set consists of total 1000 sets, the data set is divided into three parts such as 600 sets for training phase, 250 sets for testing and remaining 150 sets for checking.

Initially training data is uploaded in load data section, with the help of this data a fis is generated in generate fis section and 7 7 membership functions are selected for the input data set. In the next step an optimization method is chosen to train the generated fis i.e. back propagation method with the help of this method data is trained up to desired number of epochs for minimizing the error once the error is reduced the trained fis is tested to check either the output is in correspondence with the input. Once ANFIS gets trained with respect to the given data the trained ANFIS is applied to the existing controller of QNET VTOL 2.0. The result for ANFIS is shown and discussed in results and discussion section.

4. RESULTS AND DISCUSSION

The simulation results of proposed three tuning methods of PID mentioned earlier are displayed in this section. A comparison of results achieved by three tuning method is done on the basis of step response characteristics. To explain the findings of step response four characteristics are considered, i.e. Rise time, settling time, percent overshoot and Peak time. Fig.2 displays the outcome of built-in QNET VTOL flight control tuned manually on the basis of error and trial, as it is clear from the result that it took 1.91 seconds to rise and the first peak occurred after 7 seconds whereas the system has some overshoots i.e. 7.3 %, and the system starts to get settle down after 9.4 seconds.

Whereas in Fig.3 the result of fuzzy based intelligently tuned PID control are shown and the characteristics of step response can be found as, it took 1.2 seconds to rise, the first peak occurred at 2 seconds, there are some overshoots about 26% but the system got stable after 5.6 seconds

Contrary to conventional PID and fuzzy PID the result of ANFIS based PID controller are displayed in Fig.4 and the step characteristics are observed as, rise time is about 1.7 seconds, the first peak occurred at 1.7 seconds, overshoots about 24% and the stability time is 5 seconds.

A decrease is observed in all the characteristics of the step response. From Table.1, it is clear that the ANFIS-based auto tuned PID controller offers a smooth response than the fuzzy auto tuned PID and the current PID controller.

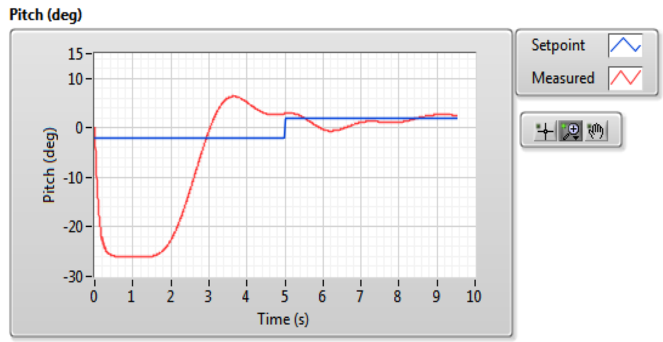

Fig.2 PID controller result

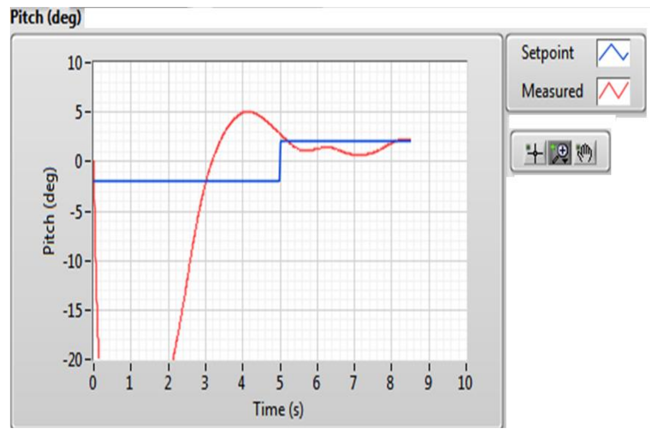

Fig.3 Auto tuned fuzzy PID controller result

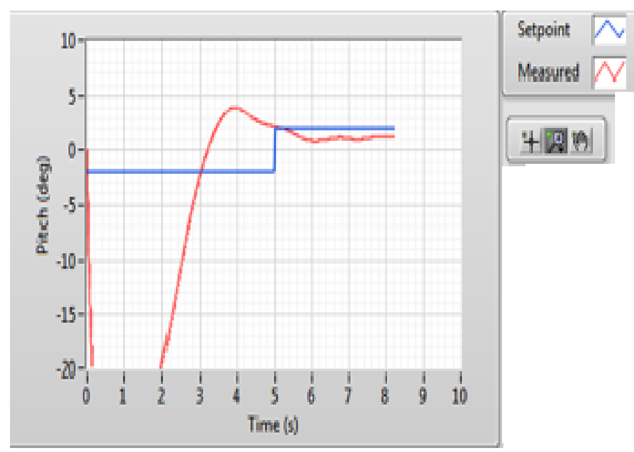

Fig.4 Auto tuned ANFIS PID controller result

Table.1 Step Characteristics

Tuning method	Rise time	overshoot	Peak time	Settling time
Heuristic method	1.91sec	7.3%	3.5 sec	7 sec
FUZZY	1.2 sec	26%	2sec	5.6sec
ANFIS	0.8 sec	24%	1.7 sec	5 sec

5. CONCLUSION

The existing PID controller of QNET VTOL 2.0 is tuned by applying three tuning methods heuristic method, fuzzy logic and ANFIS. Compared with traditional PID controllers, auto tunned Fuzzy PID and ANFIS-based PID provided better result . Performance of control schemes is evaluated with respect to rise times, settling time, percent overshoot and peak time. The results obtained demonstrated that Percent overshoot in heuristic method is less then fuzzy and ANFIS but other characteristic parameters i.e. rise time, settling time, peak time of heuristic method are unsatisfactory as compared to fuzzy and ANFIS. Heuristic method is manually tuned and time consuming but fuzzy logic and ANFIS are self-tuned and time saving. As observed from obtained characteristic parameters the fuzzy and ANFIS based PID controllers presented shorter rise time, peak time and stabilization time than the conventional PID. Results indicate that ANFIS is proven to be more optimized in comparison with conventional PID and auto-tuned fuzzy PID.

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