Fuzzy Gain Scheduling PID Control For Position of The AR.Drone

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| **Article Info** |  | **ABSTRACT** |
| ***Article history:***  Received Jun 12th, 201x  Revised Aug 20th, 201x  Accepted Aug 26th, 201x |  | This paper describes the design and implementation of fuzzy gain scheduling PID control for position of the AR.Drone. This control scheme uses 3 PID controllers as the main controller of the AR.Drone, in this case to control pitch, roll and throttle. The process of tuning parameters for each PID is done automatically by scheduling determined by Takagi-Sugeno-Kang (TSK) fuzzy logic model. This paper uses five function sets of PID parameters that will be evaluated by fuzzy logic in order to tune PID controllers. As the input of each fuzzy logic is the error position while the output is the pitch, roll and throttle of the drone. The control scheme is implemented on the AR.Drone to make it fly to forming a square in the room. The experimental results show that the control scheme can follow the desired points, and process scheduling PID parameters can be shown. |
| ***Keyword:***  AR.Drone  Fuzzy gain scheduling  PID control  Takagi-sugeno-kang fuzzy  Position control |
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1. **INTRODUCTION**

This research is motivated by the fact that in non-linear system, a single set of PID gain will only be suitable for a given operating point. When the aircraft, in this case the AR.Drone, fly on a different operating point, it would require a different PID gain. In order to make the drone fly to multiple operating points, multiple sets of PID gain is required. The scheduling mechanism is needed in order to determine the PID gain which is appropriate for the current operating point. Once the new operating point is detected, the PID gains can be changed to the appropriate values. The gain scheduler consists of multiple sets of PID gain and the logic for detecting the operating point and choosing the corresponding value of PID Gain. The purpose of this research is to experiment the implementation of fuzzy gain scheduling PID control for position control of AR.Drone in the laboratory. In this research, as the gain scheduler, Takagi-Sugeno-Kang (TSK) fuzzy logic is used. The suitable PID gain function for some operating point is determined by experimentally to get the expected transient response. Five functions of PID gain represent five operating point are used in this research.

This research uses the AR.Drone 2.0 Elite Edition which is a product of Parrot. The AR.Drone is relatively inexpensive and is equipped with onboard electronics that have a motherboard, a processor, a Wi-Fi chip, 3 axis gyroscope, 3 axis accelerometer, a sonar altimeter, and a front camera and bottom. It is also equipped with a real-time operating system that can perform multiple tasks simultaneously, such as communication with a PC via Wi-Fi, video data sampling, sensor acquisition, image processing, state estimation and closed loop control. With this communication, it is possible to transmit control commands and request navigation data of drones in the form of actual roll value, sideward speed, actual pitch value, forward speed, actual yaw rate value, yaw value, vertical rate value and altitude value [1]. Maneuver of the AR.Drone can be controlled with 4 pieces of control command that pitch, roll, yaw and throttle that has values between -1 and 1 as shown in Table 1.

Table 1. Control Command of AR.Drone

|  |  |  |
| --- | --- | --- |
| Input | Positive values | Negative values |
| Pitch | Backward | Forward |
| Roll | Right | Left |
| Yaw | Rotate CW | Rotate CCW |
| Throttle | Up | Down |

Until now, many studies have been using the AR.Drone as a platform. Mogenson [2] designed the AR.Drone LabVIEW toolkits that facilitate lecturers and researchers to control the AR.Drone using their controller design. There are 4 pieces of soft Virtual Instrument (VI), namely Main VI, Video VI, NavData VI and State VI. Main VI transmits control commands and keeps the communication channel running. Video VI is used to read UDP that contain video frame packets sent from the AR.Drone, turn it into an image or pixel clusters. NavData VI sends UDP packets to the Navdata output who ordered AR.Drone to send sensor’s data to IP address of the computer. State VI is used to estimate x, y, z position of the Navdata. Some researchers noted having designed PID and Fuzzy controller on the AR.Drone. Prayitno, *et al.* in [3] designed 2 fuzzy controllers to control the x and y position using pitch and yaw. Indrawati, *et al.* in [4] and [5] is designed and implemented three pieces of fuzzy logic control to control the position of x, y, z using of pitch, roll and vertical rate of the AR.Drone. They compared various schemes of fuzzy control to position control. Prayitno, *et al.* in [6] is designed conventional PID control and compared with fuzzy control scheme designed by Indrawati in [5]. Tang in [7] designed a PID controller for waypoint navigation applications and trajectory tracking and vision-based controller for a variety of formation flying. Abbas, *et al.* in [8] is designed controls for tracking formation quadrotor where the PID controller is implemented in quadrotor leader and directed Lyapunov controller is implemented on the followers. The artificial fish swarm algorithm is used for dynamics optimization of the parameters controllers. Seidabad, *et al.* in [9] modelled the motion of all quadrotor with Simulink. They are using two types of controllers, which are PID controller and combination of fuzzy-PID controller. The simulation results showed that the hybrid fuzzy-PID controller is more suitable when there has a turbulence. Gautam, *et al.* in [10] designed a self-tuning PID controller using EKF algorithm that is implemented on quadrotor for attitude and position control of the quadrotor. Ammozgar, *et al.* in [11] implemented Fuzzy PID Gain-Scheduled to cope with the possible failure of the actuator quadrotor. The two actuator failure schemes are designed, which are the failure of all actuators and single actuator. Prayitno, *et al.* in [12] implemented other control scheme, H-Infinity, to control pitch and roll of the AR.Drone. Hazzabi, *et al.* in [13] implemented adaptive FLC-PI, where PI controller parameters are adjusted by fuzzy gain scheduling, to control an induction motor. Syed, *et al.* in [14] applied fuzzy gain scheduling PI control based on the system’s operating conditions for controlling engine power and speed of a power-split HEV in the applied automotive field. Our paper describes the design and implementation the fuzzy gain scheduling PID control for position of the AR.Drone based on operating conditions

1. **RESEARCH METHOD**

The fuzzy gain scheduling PID control system scheme is implemented on the AR Drone is shown in Figure 1. The movement of drone to the position x, y and z are controlled by 3 controllers; each controls the pitch, roll and vertical rate. The PID controllers are used as the main controller. While fuzzy is used as the scheduler of the gain parameters of PID corresponding to earn operating point of drones, evaluated on the error position. Each fuzzy gain scheduling PID block has the same scheme. Figure 2. shows the Fuzzy gain scheduling PID for x position. For y position and z position have identical scheme. This block consists of PID signals and Fuzzy scheduler.

For the PID control, the general equation of the controller is used as shown (1) below:

(1)

where:

: Proportional Constant

: Integral Constant

: Derivative Constant

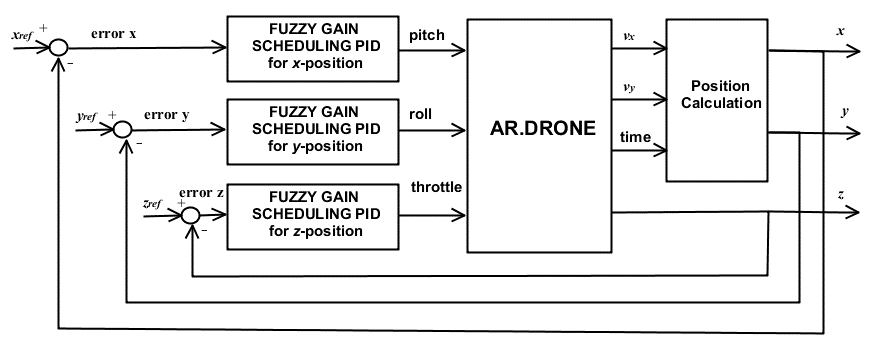


Figure 1. Block Diagram Fuzzy Gain Scheduling PID Controlled System

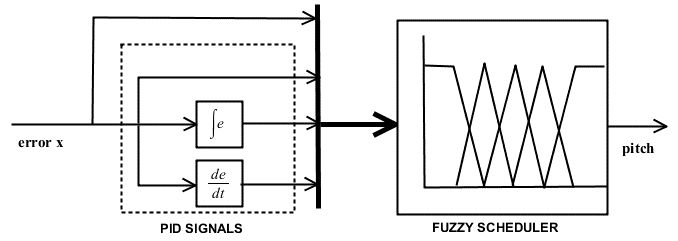


Figure 2. Fuzzy Gain Scheduling PID Scheme for -position

Takagi-Sugeno-Kang (TSK) model is used as a fuzzy scheduler. The rules of TSK model are shown in (2).

(2)

where are functions.

In the fuzzy scheduler, error position, , are used as the inputs which will be fuzzified into 5 memberships function; NB:Negative Big (-1 ≤ e ≤ -0.5), NS:Negative Small (-0.5 ≤ e ≤ 0), Z:Zero (-0.5≥e≤0.5), PS:Positive Small (0 ≤ e ≤ 0.5) and PB:Positive Big (0.5 ≤ e ≤ 1). Rules evaluation are defined by using (2), where are PID equation in (1) based on defined operating points. The operating points are represented in five membership functions above. This research using five same rules for and position control as follows:

(4)

(5)

(6)

(7)

(8)

Each rule represents one operating point which is expressed in one set PID parameter, , forming a PID equation. These parameters produce an expected transient response which corresponds to each operating point. The PID parameters is tuned experimentally by flying the AR.Drone to position, then analyzing the transient response. PID parameter tuning procedure for position can be written as follows, which is also the procedure for tuning and position. But in this research we used the same parameters for and .

1. PC at the ground station has prepared a program with PID controlled system and data acquisition
2. Setpoint position selected is ±1 meter and ±0.5 meter in accordance to the defined operating points.
3. AR.Drone is flown autonomously by using P-controller setpoint 1 meter from coordinate (0,0,1) to (1,0,1) with a particular . The data of drone is stored and the transient response is analyzed, in this case the rise time and the overshoot. It repeats 5 times. Perform this step using several and select that provide the expected transient response.
4. AR.Drone is flown autonomously using PI-controller with values obtained in step 3 and a particular from coordinate (0, 0,1) to (1,0,1). The data of drone is stored and the transient response is analyzed, in this case the rise time and the overshoot. It repeats 5 times. Perform this step using several and select that provide the expected transient response.
5. AR.Drone is flown autonomously using PID-controller with and values obtained in step 3,4 and a particular from coordinate (0, 0, 1) to (1, 0, 1). The data of drone is stored and the transient response is analyzed, in this case the rise time and the overshoot. It repeats 5 times. Perform this step using several and select that provide the expected transient response
6. Perform step 3,4 and 5 with setpoint position of 0.5 meter.
7. For -1 meter position use the result from step 5, whereas for -0.5 meter position use the result of step 6. It has been confirmed by a number of attempts which resulted in relatively similar response.
8. On 0 meter position , and is 0 (zero)
9. Tabulate the value of , and for each position representing the membership function

The result of PID parameters gained by experimentally at each operating point can be tabulated in Table 2.

Table 2. The PID Parameters

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Gain** | **Operating Points [m]** | **PID Gain** | | | **Pitch** | **Roll** | **Throttle** | **Corresponds to** | |
|  |  |  |  | **Rules** |
| I | -1 | 1.6 | 0.005 | 0.25 | Backward | Left | Down | NB |  |
| II | -0.5 | 0.5 | 0.007 | 1 | Backward | Left | Down | NS |  |
| III | 0 | 0 | 0 | 0 | Hover | Hover | Hover | Z |  |
| IV | 0.5 | 0.5 | 0.007 | 1 | Forward | Right | Up | PS |  |
| V | 1 | 1.6 | 0.005 | 0.25 | Forward | Right | Up | PB |  |

. For rules the function can be combined to get a function, as an output of the controller, as follows

(3)

1. **RESULTS AND ANALYSIS**

Fuzzy gain scheduling PID algorithm has been designed to be implemented on the AR.Drone 2.0 Elite Edition and tested indoor. The testing room size 6m x 6m x 4m with a floor made of striped line for the drone use its bottom camera to estimate and position in flight. While the position using ultrasonic sensors provided onboard the drone. In this test, AR.Drone will be flown to several positions that form a grid on the coordinates . The testing procedure is performed as follows:

1. Enter the reference position that will be addressed by the drones on the front panel of the software that has been made. In this test, a reference that will be addressed is (1.5,0,1.5) then to (1.5,1.5,1.5), and to (0,1.5,1), finally back to the initial position (0,0,1).
2. AR.Drone is flown manually to hover at position (0,0,1).
3. Switch ON auto, the AR.Drone will be autonomously flying toward predetermined reference. Change of set point is done if the position of the drone has been entered in error tolerances specified in the program,
4. Test is performed 5 times.

The test result is shown in Figure 3 below. The picture on the left is the system response in 3 dimensions while the right image is the position response of each coordinate x, y, and z. The depiction of 3D showed that the AR.Drone can go to any desired reference point but it has a relatively large error in the position z. There are 2 of 5 times where the experiment yields a relatively good transient response. Experiments 1 and 3 were late when switching to get to the point (1.5, 1.5, 1.5). In general, each point can be achieved within a rise time of 10 seconds as seen in the left image.

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Figure 3. Square shape experiments

The gain scheduling process during the test is shown in Figure 4 below. It was taken from of one of the experiments above. It is seen that the journey starts from the initial X position error is 1.5 m so PID control used Gain V, while the Y error is zero so the PID control used Gain III and errors Z 0.5 m, PID control used Gain IV. Along with drone journey towards a point of reference, the gain that works is the contribution of the two gain from appropriate membership function. Control signals, in this case, pitch, roll and throttle produced by fuzzy gain scheduling PID control is shown in Figure 5. In these control signals, there are restrictions on the control signal value ± 0.15 to avoid a collision with the wall due to the cramped indoor space.



Figure 4. Gain Scheduling Process



Figure 5. Control signal pitch, roll and throttle

1. **CONCLUSION**

This paper has implemented fuzzy gain scheduling PID control for position control of AR.Drone. The result of the test, which is to fly to the coordinates indicates that the PID gain switching process run in accordance with a predetermined operating point. AR.Drone can follow the references given well, but with a significant error.

**REFERENCES**

1. P.J. Bristeau, *et al.*,” The Navigation and Control Technology Inside the AR.Drone Micro UAV,” *18th IFAC World Congress*, 2011.
2. M. Mogenson,”The AR.Drone LabVIEW Toolkit: A Software Framework for the Control of Low Cost Quadrotor Aerial Robots,” *Master of Science Thesis, Mechanical Engineering*, TUFTS University, 2012
3. A. Prayitno, V. Indrawati and G.Utomo,”Trajectory Tracking of AR.Drone Quadrotor Using Fuzzy Logic Controller,” *Journal Telkomnika*,vol.12 no.4, pp.819-828, Dec. 2014.
4. V. Indrawati, A. Prayitno and T.A. Kusuma, “Waypoint Navigation of AR.Drone Quadrotor Using Fuzzy Logic Controller,” *Journal Telkomnika,*vol 13 no.3, pp.930-939, Sep. 2015.
5. V. Indrawati, *et al.*,” Comparison of Two Fuzzy Logic Controller Schemes for Position Control of AR.Drone,”*7th International Conference on Information Technology and Electrical Engineering (ICITEE)*, 2015.
6. A. Prayitno, *et al.*,”Comparison of PID and Fuzzy Controller for Position Control of AR.Drone,” *IOP Conf. Series: Material Science and Engineering*, vol.190, 2017.
7. S.Y. Tang,” Vision-Based Control for Autonomous Quadrotor.” *Final Report :Undergraduated Senior Thesis, Department of Mechanical and Aerospace Engineering*, Princeton University, 2013.
8. R. Abbas and Q. Wu,” Improved Leader Follower Formation Control for Multiple Quadrotors Based AFSA,” *Journal Telkomnika*, vol.13 no.1, pp.85-92, Mar. 2015.
9. E.A. Seidabad, S.Vandaki and A.V. Kamyad,” Designing Fuzzy PID Controller for Quadrotor*,”*  *International Journal of Advanced Research in Computer Science & Technology (IJARCST)*, vol.2 no. 4, pp.221-227, 2014.
10. D. Gautam and C. Ha,” Control of a Quadrotor Using a Smart Self-Tuning Fuzzy PID Controller,” *International Journal of AdVanced Robotic Systems*, vol.10, pp.1-9, 2013
11. M.H. Amoozgar, *et al.*,” Fault-Tolerant Fuzzy Gain-Scheduled PID for a Quadrotor Helicopter Testbed in the Presence of Actuator Faults,” *IFAC Conference on Advances in PID Control*, 2012.
12. A. Prayitno, V. Indrawati and C. Arron,“ H-Infinity Control for Pitch-Roll AR.Drone,” *Journal Telkomnika*, vo.14 no.3, pp.963-973, 2016.
13. A. Hazzabi, A. Laoufi, I.K. Bousserhane and M. Rahli,” Real Time Implementation of Fuzzy Gain Scheduling of PI Controller for Induction Machine Control,” *International Journal of Applied Engineering Research.*, vol.1 no.1, pp.51-60, 2006.
14. F.U. Syed, *et al.*,” Fuzzy Gain-Scheduling Proportional-Integral Control for Improving Engine Power and Speed Behavior in a Hybrid Electric Vehicle,” *IEEE Transactions on Vehicular Technology*, vol.58, 2009.