Fuzzy gain scheduling control apply to an RC Hovercraft

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ABSTRACT

The Fuzzy Gain Scheduling (FGS) methodology for tuning the Proportional-Integral-Derivative (PID) traditional controller parameters by scheduling controlled gains in different phases, is a simple and effective application both in industries and real-time complex models while assuring the high achievements over pass decades, is proposed in this article. The Fuzzy logic rules of the triangular membership functions are exploited on-line to verify the Gain Scheduling of the Proportional-Integral-Derivative controller gains in different stages because it can minimize the tracking control error and utilize the Integral of Time Absolute Error (ITAE) minima criterion of the controller design process. For that reason, the controller design could tune the system model in the whole operation time to display the efficiency in tracking error. It is then implemented in a novel Remote Controlled (RC) Hovercraft motion models to demonstrate better control performance in comparison with the PID conventional controller.

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1. INTRODUCTION

PID controller is one of the most popular controller and is applied in many operation conditions due to its simple structure and effectiveness [1]. In literature, PID controllers is literally divided into two main categories. The first is the controller gains, which have been tuned or chosen by traditional ways, are fixed during the running time and Ziegler-Nichols tuning methodology is the best representative off-line formula [2]. In this category, the PID controller gain designs are simple and cannot always effective, it is also mean that different gains give the different system's response. The controller designs in the second category have a similarity structure, however, its parameters are adapted on-line throughout the operating time. With the purpose of getting the optimal performance in terms of accuracy, stability and satisfatory response, the control system must carefully consider the compromise between the settling time and the overshoot. Thus, the PID parameters design of the new operating conditions have spent lots of time for tuning [1].

Gain scheduling is regarded as an excellent controller design approaches in [2, 3]. It can be classified as “divide-and-conquer” control procedure type, in which some linear sub-problems are combined to implement the non-linear design operation [2] and various gains of controllers are utilized in every regions. The critical point in building a good controller is determining the scheduling variables, which have suitable priori insight to the process dynamics [3]. State variables, errors and their changing rates are commonlu used variables [4-7]. Designers can determine the regions by magnitudes of scheduling variables or establish the regions by local linearization of dynamic model in the neigbor of some special operating points [2, 3].

In this work, we intend to create a simple and effective control sytem for quick positioning utilizing PID controller‘s characteristics. For fast convergence of the controlled system, we set gains to have large magnitude as scheduling variables are high. Similarly, for system to be settling with less fluctuation, we keep the gains have low magnitude when scheduling parameters are low. This scheme practically works in tracking. Unfortunately, this conventional approach can not satisfy the fast-rising response requirement in the beginning phase since both the time derivative and its error are too low to obtain acceptable large control output. Therefore, time delay is not very different with traditional PID controller. Actually, the setpoints in each movement could be the most suitable scheduling variable that satisfies our goal. Orelind et al. [8] first designed optimal PID gain schedule for the hydro-generators system. In [9], Beaven et al. use the gain scheduling of setpoints in high-speed independent 2-phase drive. Situm et al. [10] applied this method to servo pneumatic position control. Later, Dounis et.al. [11] and Vijaya Chandrakala et.al. [12] exploited adaptive fuzzy gain scheduling to the energy systems. Next, Kankgasabai and Jaya [13] and Ahmad et. al. [14] then control the PID gains with this technique for MIMO process control. Currently, Yao and Lakerveld employ this method to microfluidic devices [15]. Yilmaz et.al. also exploit the gain-scheduling PID controllers for Z-source inverter [16].

In our research, we proposed to apply fuzzy gain scheduling technology for designing a motion controller. Firstly, we created a PID controller that has large magnitudes of proportional and integral gains and low magnitude of derivative gain in the motion initialization period. Later, the fuzzy gain scheduling technique is applied to slowly increase the derivative gain as well as reduce the proportional and integral gains until another setpoint is met. The first setpoint is then chosen at the ending part of the trapezoid curve of constant speed region. By this way, the speed could be kept constant as less fluctuation as possible in the unchanged speed region. We aim to build a moving system to come to the target location and obtain settling state in a short period. The key technique in proposed approach is the fuzzy logic-based technique of gain scheduling. After finding the suitable regions for implementing gain scheduling. The suitable controller gains are determined to achieve our goal. The Hovercraft motion model [17-22] is utilized to demonstrate the effectiveness of this novel method. It is then compared with the traditional PID auto-tuning control.

This work is presented as follows: In section 2, the development of fuzzy gain scheduling scheme for dynamic reset of PID controllers is proposed. In section 3, we present how to configure the RC Hovercraft model. In section 4, we present the simulation results of the proposed controller system performance. Finally, conclusions are discussed in section 5.

2. RESEARCH METHOD

2.1. PID controller

In literature, discrete-time PID controller is usually defined as:

$$u\left(n\right)=K_{\mathrm{P}}e\left(n\right)+K_{I}T_{S}\sum_{i=1}^{n}e(i)+K_{\mathrm{D}}\frac{e\left(n\right)-e\left(n-1\right)}{T_{S}} \tag{1}$$

where, u(n) is known as the control signal and e(n) represents the error input. T_s is the sampling period. Moreover, the proportional, integral and derivative gains are represented by K_P, K_I and K_D, respectively. These gains can be tuned to output various responses of a specific process.

2.2. Fuzzy gain scheduling

In many schemes of gain scheduling design process, suitable regions for the variable need to be determined [7]. The T-curve (trapezoidal velocity curve) as shown in Figure 1, which has three parts: acceleration $t \in [0, t_1]$, constant speed $t \in [t_1, t_2]$, and deceleration $t \in [t_2, t_3]$, is chosen to find out the regions. In the deceleration phase $[t_2, t_3]$, we apply fuzzy logic technique (inference rule) to change these parameters linearly and continuously. The two membership functions μ_1 and μ_2 are demonstared in Figure 2. The Fuzzy logic inference rules are expressed as followings:

If $p<p_1$, then $\mu_1=1$ and $\mu_2=0$.
If $p_1 \le p \le p_2$, then $\mu_1=\frac{p_2-p}{p_2-p_1}$ and $\mu_2=\frac{p-p_1}{p_2-p_1}$.
If $p > p_2$, then $\mu_1=0$ and $\mu_2=1$.

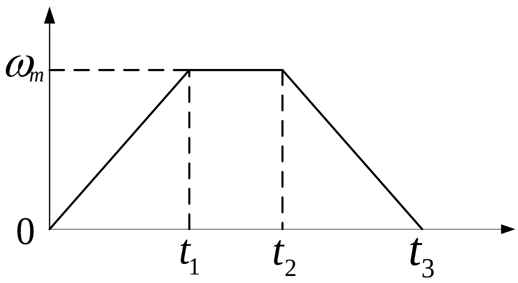


Figure 1. Trapezoidal velocity/position curve

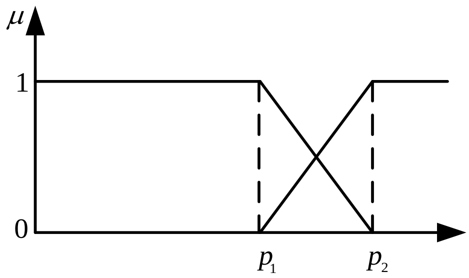


Figure 2. Membership functions vs set points

The desired positions of the moving model, which based on the above fuzzy logic rules, are employed to evaluate the response performances. The proposed Fuzzy-PID control system block diagram, which included two fuzzy logic membership functions, is demonstrated as shown in Figure 3. Specifically, weighting μ_i of the i-th membership function depends on the current command position $p=y_d(t)$. We choose $\mu_1=1$, and$\mu_2=0$ in phase I of initial PID gains. In phase II, $\mu_1 = \frac{p_2 - p}{p_2 - p_1}$, and $\mu_2 = \frac{p - p_1}{p_2 - p_1}$ are chosen as the blended gains. The second set of initial gains in phase III are $\mu_1 = 0$, and $\mu_2=1$. The PID gains can be calculated in any time point and the subscripts 1 and 2 of the PID gains represent the membership function I and II in (2).

$$\begin{cases} K_P = \sum_i \mu_i . K_{P_i} \\ K_I = \sum_i \mu_i . K_{I_i} \\ K_D = \sum_i \mu_i . K_{D_i} \end{cases} \tag{2}$$

The standard criterion ITAE [23-25], which are multiply by time at each sampling data and express as $ITAE = \int_0^{\infty} t.\left|e(t)\right|.dt$, is chosen as the eye to show the less error for both controller design methods Ziegler-Nichols and Fuzzy Gain Scheduling, which applied to the RC Hovercraft motion models.

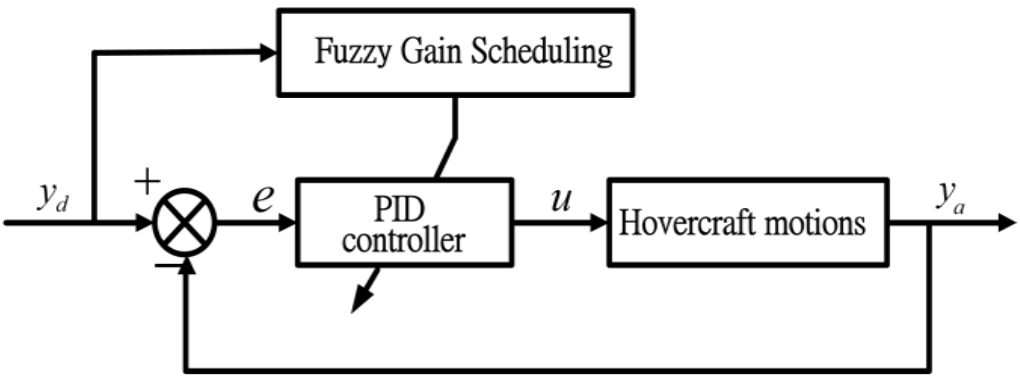


Figure 3. The fuzzy gain scheduling-PID controller diagram

3. RC HOVERCRAFT CONFIGURATION MODEL

A hovercraft, also known as an air cushion vehicle (ACV), consists of rotors and a cushion. The hovercraft can float and cruise smoothly on various surfacec such as rough land, water, sand beach, as well as the ice [17-22] due to the inside air pressure of the cushion. The lift propeller provides the internal cushion pressure for operating a long period of time. A hovercraft turning typically is done by directing the thrust air flow through rotor duct fan and steering by a tilt servo motor placed at the rear. The subsequent momentum generated is used to maneuver the craft. Though many modern technologies are utilized, the hovercraft requires an advanced maneuvering system to achieve optimized performance. Hence, this paper presents an agile autonomous hovercraft model. It has a single tilt servo motor, which is equipped on the fin tail. The rotor duct fan is settled along the y-axis and the propeller is attached along the z-axis, as shown in Figure 4.

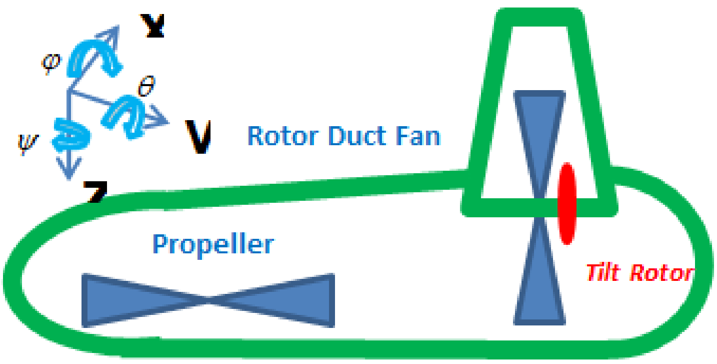


Figure 4. The Hovercraft configuration model

The dynamic of the Hovercraft model is derived from [19-21] and the vehicle is demonstrated utilizing right-hand coordinate system. Additionalyy, positive x-axis shows the lateral, namely sway motion or surge position. Positive y-axis goes along to the hovercraft body, namely surge motion or sway position. Besides, positive z-axis is oriented downwards. The Hovercraft's kinematics can be expressed as:

$$\begin{cases} \dot{x} = u\cos\psi - v\sin\psi \\ \dot{y} = v\cos\psi + u\sin\psi \\ \dot{\psi} = r \end{cases} \tag{3}$$

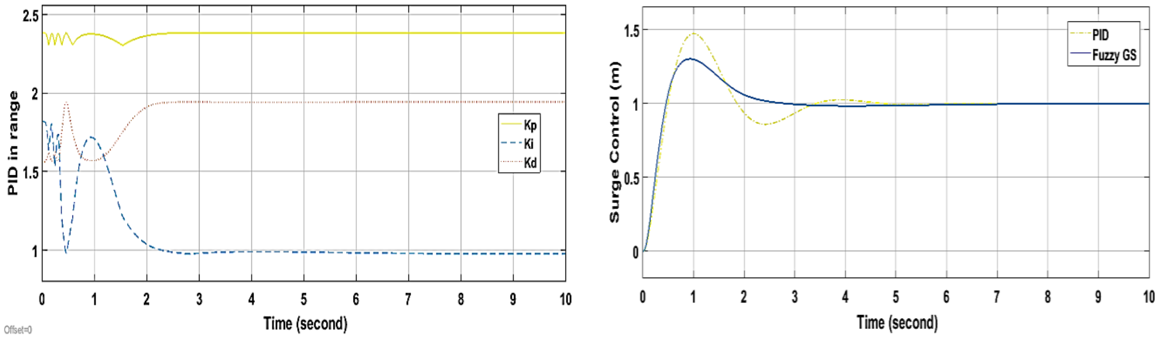
where $r \in \Re$ is called as angular velocity, $u \in \Re$ and $v \in \Re$ are linear velocities in surge direction and sway direction, respectively. Using (1), the kinetic and potential energy are derived to define the Lagrange L=T-V and by applying Euler-Lagrange formulation:

$$M(q)\dot{q} + C(q,\dot{q})q = \begin{bmatrix} F \\ \tau \\ 0 \end{bmatrix} \tag{4}$$

where $F \in \Re$ represents the control force along the surge direction, $\tau \in \Re$ is the torque moment in yaw action. The torque control depends on F and is at right angle to the center line of the hovercraft propeller.

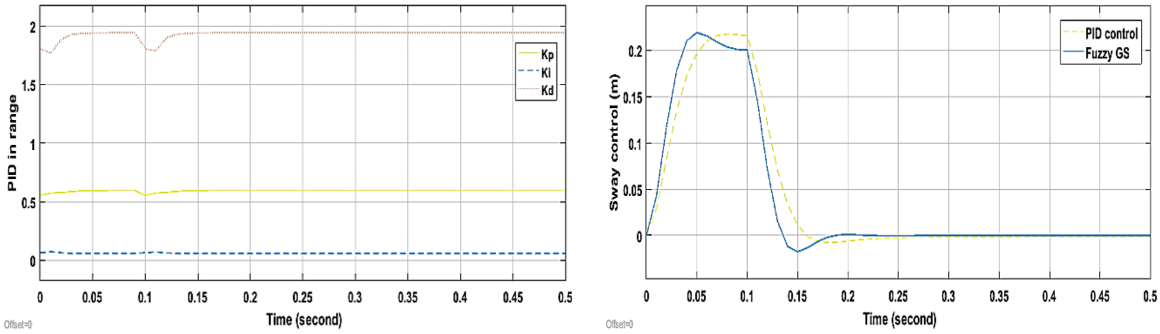
4. RESULTS AND ANALYSIS

The simulation parameters of the Hovercraft are derived from [19-21] and denoted shortly with the mass m = 2.1 kg and the inertia moment I = 0.000257. Based on the Hovercraft model, the PID gains are chosen in [0, 20] range. The proposed control performances in Figures 5, 6, and 7 are displayed in each channel: surge position x, sway position y and yaw angle, respectively. We then use Matlab to implement the model. The numerical simulation results have proved that the proposed controllers show significant stability and robust performance response. The proposed Fuzzy Gain Scheduling for PID controller simulation have all received results have the maximum response time, without overshoot and less error, are just after the first second at all. The optimal gains issue is considering in the future work.



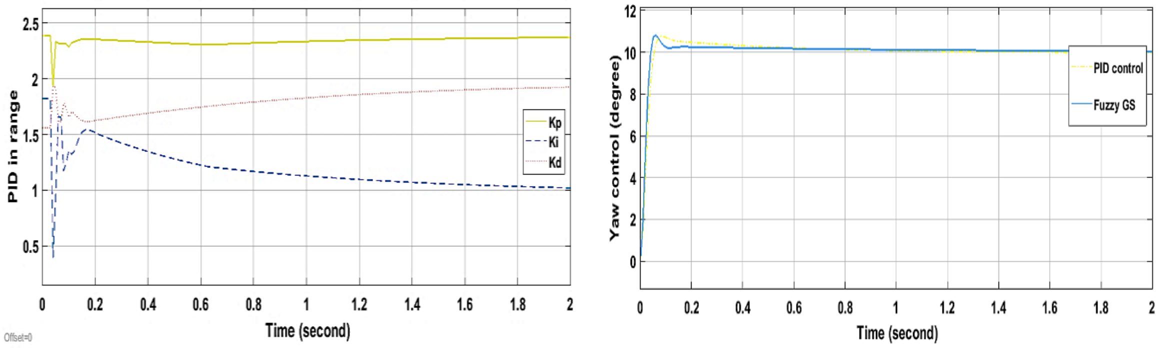
(a) (b)

Figure 5. (a) Fuzzy gain scheduling tuning pid gains, (b) surge control



(a) (b)

Figure 6. (a) fuzzy gain scheduling tuning PID gains, (b) sway control



(a) (b)

Figure 7. (a) fuzzy gain scheduling tuning PID gains, (b) Steering-yaw control

5. CONCLUSION

In this article, the Fuzzy Gain Scheduling is extensively to verify the conventional PID control parameters. The scheme has been tested on the motion models of the RC Hovercraft and the reasonable results are obtained. Thus, the operation time is prominently decreased and the goal of fast positioning is achieved. This method, although is simple but effective in the most control systems. It would be helpful to promote control system.

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REFERENCES

[1] Z.-Y. Zhao, M. Tomizuka, and S. Isaka, “Fuzzy gain scheduling of PID controllers,” *IEEE Transactions on Systems,Man and Cybernetics*, vol. 23, no. 5, pp. 1392-1398, 1993.
[2] J. G. Ziegler and N. B. Nichols, “Optimum settings for automatic controllers,” *Transaction of ASME*, vol. 64, pp. 759-768, 1942.
[3] D. J. Leith, and W. E. Leithead, “Survey of gain-scheduling analysis and design,” *International Journal of Control*, vol. 73, no. 11, pp. 1001-1025, 2000.
[4] K. H. McNichols, and M. S. Fadali, “Selecting operating points for discrete-time gain scheduling,” *Journal of Computers and Electrical Engineering*, vol. 29, no. 2, pp. 289-301, Mar. 2003.
[5] K. J. Åström and B. Wittenmark, *Adaptive Control*, 2nd edition, Addison-Wesley, 1994.
[6] C. Ling, and T. F. Edgar, “Experimental verification of model-based fuzzy gain scheduling technique,” *American Control Conference*, vol. 3, pp. 2475-2480, Jun. 1994.
[7] T. Y. Huang and H. K. Tran, “Optimization of Setpoint-Based Fuzzy Gain Scheduling and Its Application to a Linear Stage,” *7th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, 2012.
[8] G. Orelind, L. Wozniak, J. Medanic, and T. Whittemore, “Optimal PID gain schedule for hydrogenerators-design and application,” *IEEE Transactions on Energy Conversion*, vol. 4, no. 3, pp. 300-307, 1989.
[9] R. W. Beaven, M. T. Wright, S. D. Garvey, M. I. Friswell, and D. R. Seaward, “The application of setpoint gain scheduling to high-speed independent drives,” *Control Engineering Practice*, vol. 3, no. 11, pp. 1581-1585, Oct. 1995.
[10] Z. Situm, D. Pavkovic, B. Novakovic, “Servo pneumatic position control using Fuzzy PID gain scheduling,” *Transactions of the ASME, Journal of Dynamic Systems, Measurement, and Control*, vol. 126, no. 2, pp. 376-387, 2004.
[11] A. I. Dounis, P. Kofinas, C. Alfodimos and D. Tseles, “Adaptive fuzzy gain scheduling PID controller for amximum power point tracking of photovlotaic system,” *Renewable Energy*, vol. 60, pp. 202-214, 2013.
[12] Vijaya Chandrakala, S. Balamurugan and K. Sankarannarayanan, “Variable structure fuzzy gain scheduling based load frequency controller for multi area hydro thermal system,” *International Journal of Electrical Power and Energy Systems*, vol. 53, pp. 375-381, 2013.
[13] N. Kanagasabai and N. Jaya, “Fuzzy Gain Scheduling of PID controller for a MIMO Process,” *International Journal of Computer Application*, vol. 9, no. 10, pp. 13-20, 2014.
[14] M.A. Ahmad, S.I. Azuma, and T. Sugie, “Performance analysis of model-free PID tuning of MIMO systems based on simultaneous perturbation stochastic approximation,” *Expert Systems with Applications*, vol. 41, no. 14, pp. 6361-6370, 2014.
[15] Y. Gao and R. Lakerveld, “Experimental validation of scheduled PID control for directed self-assembly of colloidal particles in microfluidic devices,” *In Computer Aided Chemical Enginee*ring, vol. 44, pp. 2455-2460, 2018.
[16] A.R. Yılmaz, B. Erol, A. Delibaşı and B. Erkmen, “Design of gain-scheduling PID controllers for Z-source inverter using iterative reduction-based heuristic algorithms,” *Simulation Modelling Practice and Theo*ry, vol. 94, pp. 162-176, 2019.
[17] J.R. Amyot, “Hovercraft Technology, Economics and Applications,” *Elsevier Science Publishing Co.*, New York, 1989.
[18] H. Nakamura, H. Kayanuma, S. Kimura, M. Kosugi, “A new process for small boat production based on aluminum hot-blow forming,*” Journal of Materials Processing Technology*, pp. 196-205, 1997.
[19] Hebertt Sira-Ramirez and Carlos Aguilar Ibanez, “On the control of the Hovercraft,” *Dynamic and Control*, Kluwer Academic Publishers, vol. 10, pp. 151-163, 2000.
[20] Rashid, Aras., Kassim, Ibrahim, Jamali, “Dynamic Mathematical Modeling and Simulation Study of Small Scale Autonomous Hovercraft,” *International Journal of Advanced Science and Technology*, vol. 46, Sep. 2012.
[21] Dictino Chaos, David Moreno-Salinas, Rocío Muñoz-Mansilla, and Joaquín Aranda, “Nonlinear Control for Trajectory Tracking of a Nonholonomic RC-Hovercraft with Discrete Inputs,” *Mathematical Problems in Engineering*, vol. 2013, pp. 1-16 2013.
[22] D.I. Garcia and W.N. White, “Control design of an unmanned hovercraft for agricultural applications,” *International Journal of Agricultural and Biological Engineering*, vol. 8, no. 2, pp. 72–79, 2015.
[23] S. Skogestad, “Simple analytic rules for model reduction and PID controller tuning,” *Journal of Process Control*, vol. 13, pp. 291-309, 2003.
[24] F.G. Martins, “Tuning PID Controllers using the ITAE Criterion,” *International Journal Engineering Educatio*n, vol. 21, no. 5, pp. 867-873, 2005.
[25] W. Tan, J. Liu, T. Chen, and H.J. Marquez, “Comparison of some well-known PID tuning formulas,” *Computation Chemical Engineering*, pp. 1416–1423, 2006.

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