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DESIGN FUZZY PID CONTROLLER FOR NONLINEAR SYSTEMS

*Sami Abdulaziz Ali

Assist Lect., Baqubah Technical Institute, Middle Technical University, Diyala, Iraq

Abstract: The Proportional, Integral and Derivative (PID) controller is one of the most common controllers that is used by the industry. In nonlinear systems, the PID controller performance is weak unlike its performance with the linear systems which is very well. In this research, we are dealing with the PID parameters characterization. Fuzzy PID controller is proposed to enhance the performance of the conventional PID controller. The proposed controller is done by investigate a partial fuzzy PID controller and compare it with classical PID. To distinguish the efficiency and robustness of the proposed controller for closed loop systems. The proposed controller is tested for both linear and nonlinear systems with success with both. The results show that the proposed fuzzy PID controller is performing better than classical PID controller.

Keywords: *Fuzzy logic; Linear Systems; fuzzy PID controller; non-linear Systems; PID controller*

تصميم المتحكم النسبي الشامل في الانظمة الغير خطية

الخلاصة: وحدة التحكم النسبي الشامل والمشتق هي واحدة من أكثر وحدات التحكم شيوعا. يتم استخدام هذا المتحكم في كثير من الصناعات. أداء هذا المتحكم في الأنظمة الغير خطية ضعيف على عكس أدائه مع الأنظمة الخطية الذي هو جيد جدا. في هذا البحث، نقترح وحدة تحكم جديدة لتحسين أداء هذا المتحكم. للتأكد من كفاءة وحدة التحكم المقترحة يتم مقارنة النتائج مع وحدة التحكم الأصلية باستخدام نفس النظام وفي نفس الظروف جراء. للتمييز بين كفاءة ومتانة وحدة تحكم المقترحة والمتحكم التقليدي لأنظمة الحلقة المغلقة يتم اختبار وحدة التحكم المقترحة لكل من الأنظمة الخطية وغير الخطية لضمان نجاحه مع كليهما. وأظهرت النتائج أن وحدة التحكم المقترحة تقدم أداء أفضل من المتحكم التقليدي.

1. Introduction

Several approaches are proposed during the design and analysis of the complex nonlinear system. Various difficulties encountered during it. For nonlinear or highly uncertain process systems, the PID controller cannot provide high performance because of its design and characteristics. A non-conventional control technique should combine with the PID controller to be able to work with non-linear systems [1]. To make the controller robust, fuzzy logic is used to increase the performance of the system particularly [2]. Fuzzy logic is applied in many research area and it approved its successfully within them. Since 1974 when Mamdani is introduced, the fuzzy logic start used widely in consumer products [3]. The objective of this research is to design PID controller depending on combining conventional and non-conventional control techniques. The fuzzy PID controller proportional parameters proportional (P), integral (I) and conventional derivate control parameters (D); which will be used to enhance the performance of control system. The advantage of proposed fuzzy PID

* Ssaziz1962@gmail.com

controller over the classical PID controllers that are in markets is that the fuzzy algorithm will regulate conventionally. The parameter P of fuzzy has an important role in enhancing the accelerating response time and overshot of the system. The study state error is reduced by the conventional integral I. Where the conventional D is used to practice the stability of the response [4]. Based on original PID controller, there is only one parameter that should be adjusted. Same simple structure is used to design the fuzzy PID controller with a little enhancement on the design. The hardware design will have kept same as original PID implementation [5], [6].

The paper is organized by the following sections: In section one different approaches of control system is presented. Section two will cover in details conventional PID controller. Fuzzy P.I.D controller is presented in section three. Finally, the comparison between the approaches for performance of nonlinear systems are presented.

2. Control Systems

Depending on previous researches, there is no typical linear system; all the dynamic systems are nonlinear [7]. The conventional PID controller is the most widely control system that is used by the industry. The reason of that are due to its easy design, inexpensive cost and simple control structure. It is important to use conventional controllers due to parameters fluctuations.

Different control strategies are presented in this section. For ordered systems, H_∞ control is used because of its acceptable level of performance and to ensures stability despite neglected dynamic process and uncertainties in parameters [8]. The main objective of using sliding mode

control is to attract system states in selected region. The designed law control system will work on maintaining the selected area of the system continuously [9].

To provide a complex study system with dynamic behavior, there are many non-conventional control methods that can presents a relevant solution. Fuzzy control is one of these non-conventional methods. To implement a simple and efficient control systems using fuzzy control, the human expertise operation is used to handle the process [10], [11]. Fuzzified PID controller on the closed loop system performance is selected in this research.

2.1. *Nonlinear Systems Performance with PID Controller*

P.I.D controller count as the standard conventional control process. The following formula represent the controller signal u for the PID controller.

$$u = k_p e(t) + k_i \int e(t)dt - K_d \frac{d}{dt} \qquad (1)$$

Where K_p is the proportional gain, K_i the integration gains and K_d the derivative gain. Here are different approaches used to determine controller parameters. According to desired performance, these approaches could be optimal adapted, unoptimal dynamic, pole placement and linearization with PID parameters. For example, pole placement approach which is a method employed in feedback control system to place the closed-loop poles of a plant in predetermined locations in the s-plane. This method is applied on the following transfer function of oscillating linear system.

$$G(s) = \frac{1}{s^3 + 5s^2 + 12s + 6} \tag{2}$$

The selected poles of the closed loop system are (-1, -1/2, -1/3 and -1/4) which are arbitrary selected to show the system's behaviour. The formula of designed PID controller is shown below:

$$G_{(s)} = \frac{\alpha s^2 + \beta s + \gamma}{s} \tag{3}$$

The result of the design system is shown below:

$$u(t) = 8s + \frac{4}{3} + \frac{1}{3s} \tag{4}$$

Fig. 1 shows the PID controller system design.

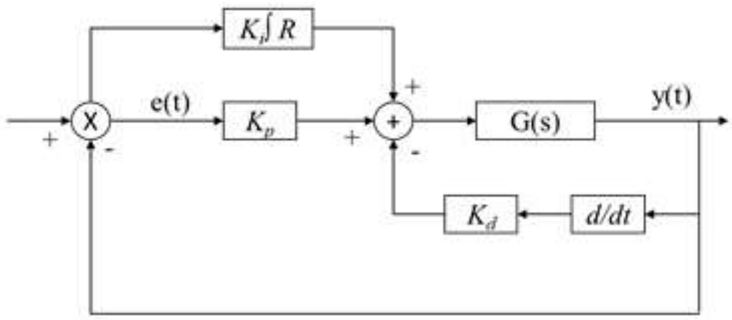

Figure 1. PID controller system

Fig. 2 shows the step response of the PID controller. It is also shows a closed loop response time of 4 sec. To calculate the fluctuation of parameters 0.5 is added to the coefficients of polynomial ($s^3 + 5s^2 + 12s + 6$) which becomes ($s^3 + 5.5s^2 + 12.5s + 6.5$).

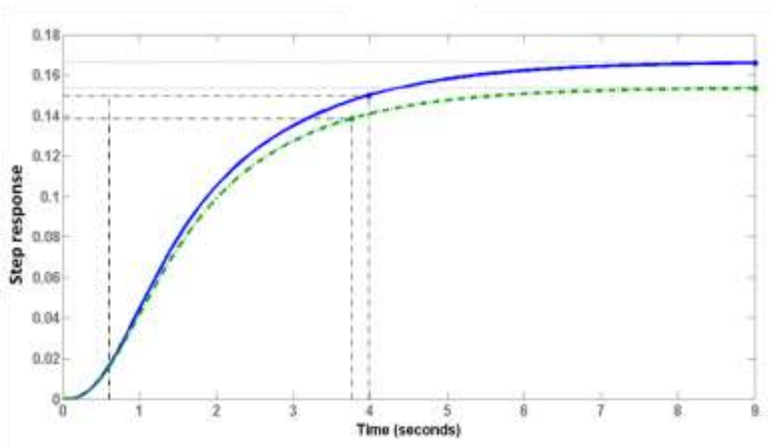

Figure 2. Response of initial system

Where the blue line represents the step response of selected transfer function and the green dot line represent the fluctuation parameters. Fig. 3 shows the difference between the system response *y(t)* and the fluctuated system response $y_f(t)$.

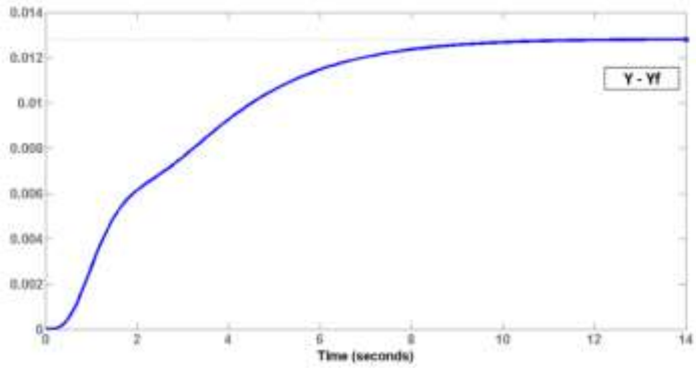

Figure 3. Difference between the step response of the system and fluctuated response

From figures 2 and 3 we can see that at figure 2 both systems are starts from same point and they are very close to each other. By time the step response are going far from each other. Figure 3 shows the difference between these two systems represented by both systems are stating from same point where the difference is zero then by time the gap between them is increasing and the difference value becomes bigger.

3. Fuzzy PID Controller

Partial fuzzy PID controller is constructed and implemented to the system. A merge of a classical control technique and the non-conventional technique is considered to adapt the controller to operating requirements [13]. A fuzzy and PID controller are combined to improve the performance of the system. The proportional term of the proposed controller is using instead of conventional strategy the fuzzy logic control. The other two parts of the controller which are integral and derivative did not change. Fuzzy logic contains many inference rules and degree of membership function possibilities which leads to good diversity of the system characteristics. The formulation of the controller is containing two inputs which are e and e^{-} and one output which is z. the interval normalization of this variables is assumed to [-1, 1]. A comparison between the proposed controller and classic PID controller will done in this study. The variables e, e^{-} and z of the fuzzy system are based on three sets distribution with the domain normalization [-1, 1]. Trapezoidal shape is selected to represent the membership function of the controller. Figures 4, 5 and 6 presents the membership function of the proposed controller.

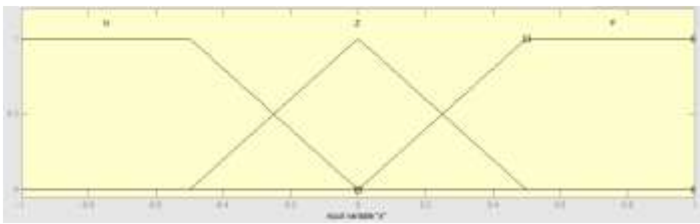

Figure 4. Membership function of input *e*

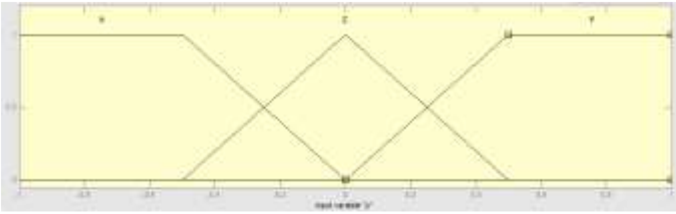

Figure 5. Membership function of input e^{-}

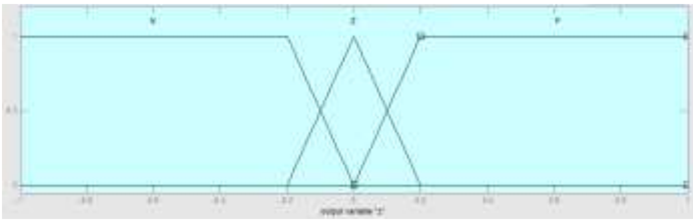

Figure 6. Membership function of output *z*

Each variable has three subsets which are leads to inference rules. Fuzzy sense is describing the control actions. To convert the fuzzy control actions into an output fuzzy controller, defuzzification method is required. Centroid which is the widely defuzzification method is used for incremental fuzzy controller. Three subsets are considered for each variable that are leading to inference rules which is presented in table 1. Max- Min method is the commonly used inference rules.

Table 1. Inference rule

-e\e	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

Fig. (7): represents the closed loop control of partial fuzzy PID for the proportional parameter of the third order oscillating linear system. The designed model is like the classical PID controller in its architecture, the only differences is by adding the fuzzy logic (FLR) to the PID controller.

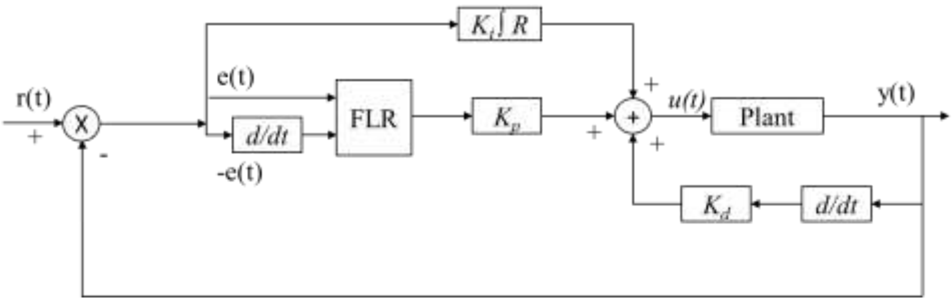

Figure 7. Fuzzy P.I.D controller

Fig.8 shows the comparison of response for the two systems that are shown in Fig.1 and Fig.7.

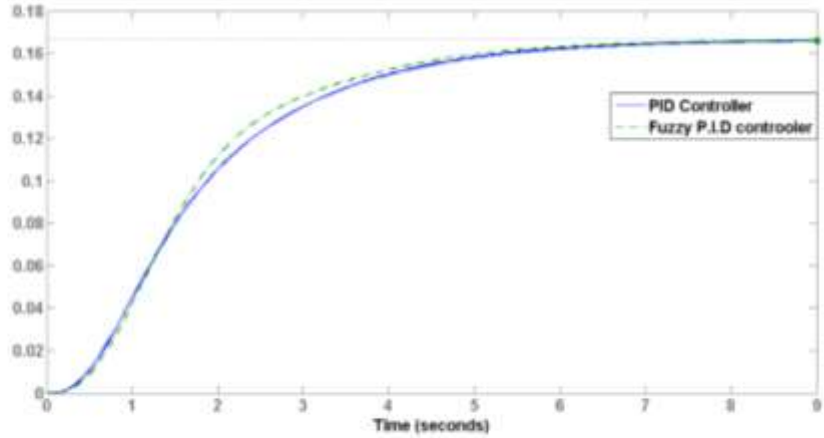

Figure 8. Response time of PID and fuzzy P.I.D Controllers

The response time for the proposed fuzzy PID controller is about 3.7s which is less than time response for the classic PID controller for the same system that was 4s. The conventional PID is very efficient because it is linear system despite that fuzzy PID controller enhance the response time of the system with small value.

4. Nonlinear System and Controller Validation

To approve the robustness and effectiveness of the fuzzy P.I.D controller, we will apply it on nonlinear system that is shown below:

$$\ddot{y} + 2\xi\sigma\acute{y}y + \sigma^2 y = \sigma^2 u \quad (4)$$

Where zero is the initial values of the system and σ = ξ =1. According to the schemes of the systems, the closed loop system behavior is observed by regulating the ξ value. The classical PID controller's parameters value are selected according to pole placement as follow; K_p = 1.3, K_i = 1 an K_d = 0.9. Different values of ξ is tested to test the robustness of the fuzzy P.I.D controller that is proposed. Table 2 shows the overshoot and response time of different values of ξ.

Table 2. Response time and overshoot for different ξ

	PID controller				Fuzzy PID controller			
ξ	0.3	0.7	1	1.3	0.3	0.7	1	1.3
Response time (s)	Oscillate	22.8	8.8	10.87	6.5	6.75	4.3	5.13
Overshoot	2.9	1.4	1.3	1.2	1.5	1.3	1.05	1.02

The table shows the fuzzy PID controller offer a good performance compare the classical PID controller with different values of ξ. The fuzzy PID controller is more robust than classical PID with ξ = 0.3, the classical PID controller is still oscillating while the fuzzy PID controller reaches to the set point within 6.5s; this shows the proposed controller robustness.

5. Signal to Noise Ratio Estimation

The regulator behavior is changing under real stochastic noise. Therefore, to evaluate the output noise of the system, Signal to Noise Ratio (SNR) is used. The estimation of signal to noise ratio will discussed depending on [14].

$$SNR = 10log_{10}(\frac{\mu^2}{\lambda^2}) \quad (5)$$

Where μ represents signals mean and λ is the noise (N) standard deviation. several tests are performed to test the proposed controller robustness. By adding Gaussian noise to the output signal, these tests are done. By adding 15% Gaussian noise to the reference signal, the SNR will be 31.55 dB with 44% of noise. Fig. 9 shows the step response regulation after adding noise to the signal.

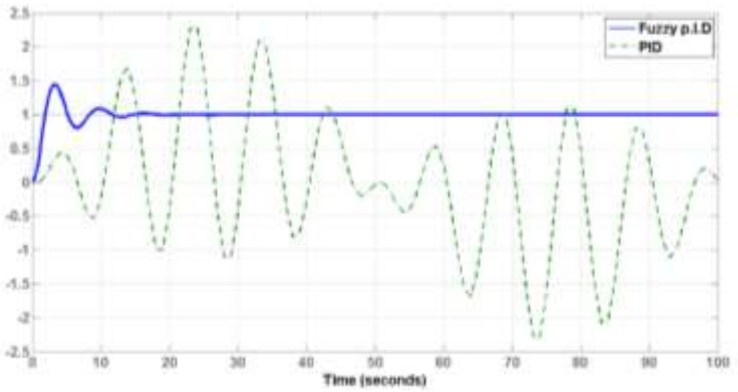

Figure 9. Step response with white Gaussian noise for ξ = 0.3

Fig. 10 shows the step response of both systems with ξ = 1. By increasing the value of ξ both controller performs well but fuzzy PID controller still more stable, less variation time and generally better than normal controller.

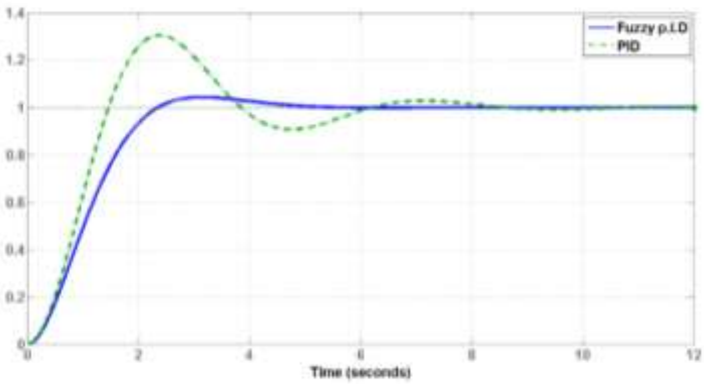

Figure 10. Time response with ξ = 1

6. Conclusion

Partial fuzzy P.I.D controller is introduced in this paper. The proposed controller is based on classical PID controller, the only different is the term P of P.I.D is replaced by fuzzy logic controller. Fuzzy P.I.D and conventional PID controller are applied on two systems one of them is third order linear system and the second one is nonlinear system to show the robustness of the proposed controller. The comparison shows that fuzzy P.I.D is better than conventional PID in term of performance. The results show the robustness and efficiency of the proposed fuzzy P.I.D regulator over the classical PID controller.

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