Segmentation of Fuzzy Logic Inference to a Conventional PID Controller for Nonlinear pH Neutralization Application

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Abstract: A pH control is a challenging system in nature due to the titration characteristic which is highly nonlinear and the response is varying with time. The study focus on the segmentation of fuzzy logic to improve nonlinear control for conventional PID controller in pH neutralization system. The conventional controller which integrate with the fuzzy logic approximation is proposed in this paper. In addition, the designed controller will be evaluated for servo and regulator cases. The performance and the analysis will be compared with a conventional PID controller in the same control system setup. As a result, the proposed controller show superior performance in all analyzed cases and able to overcome nonlinear effect in pH neutralization application.

Keywords:*pH neutralization, nonlinear control, fuzzy logic, hybrid controller*

I. INTRODUCTION

Nowadays, the pH control is taking an important role in wastewater treatment, chemical industry, oil and gas and pH neutralization plant. A control system of pH neutralization is needed to maintain and adjust the pH value of titration reactor before it discharge to the environment [1]. This is due to the environmental regulation to safe guard the environment. At present, a regulation has become more stringent following the growth of the industry. The acidic and bases solutions cannot be directly thrown and discharge to the river, pond and environment. This may corrode and is harmful to human and earth. Due to this, the industry has adopted a pH neutralization system to properly manage the waste solution.

A pH neutralization process is highly nonlinear dynamic or nonlinear characteristic. This is because the pH in the titration curve is showing S-shaped curve which has many regions and different gradients in the profile. Besides that, the titration curve is time varying because the flow rate of buffer capacity is adding [2]. Then, the pH value is a very sensitive point on the curve and is sensitive to the disturbances near the set point where the pH value is 7. Therefore, an advanced controller of pH neutralization system is required.

The fuzzy logic is a nonlinear system and it is using a linguistic method to compute certain output. Many problems [3] that inherit nonlinear characteristic such as pH neutralization can be solved by fuzzy logic [4]. "**If** (condition) – **Then** (action)" rule statement is used to evaluate input(s) and output(s) with specific condition and action. Each of the rule statement will give result base on the input implication and fuzzy inference. Systematic method has been introduced to design a fuzzy controller[5]. This method is robust and stable due to the implementation of universal gain after the controller output which is able to drive the process-variable to the reference value. Fuzzy logic system could also be used to improve the conventional controller or other's controller strategy. Many types of control system mechanisms have been introduced and this strategy promised stability and robustness in controlling dynamic either online or off-line. Like Lyapunov technique [6], sliding gain technique [7], self-tuning gain [8] and many more. Hybrid technique with fuzzy estimation has been imposed in controlling pH neutralization[9], whose conducting a set point tracking and load disturbance with acceptable successful achievement. Unfortunately, the test is in bench scale 1-liter reactor which is limited to robustness problem as in industrial scale. The work on algorithm of universal learning network (ULN) technique for pH control has been introduced by [10]. The technique works on selecting a time delay for ULN closed loop PID controller off-line. As a result, this technique is able to control along the design controller trajectory. A nonlinear controller has been develop [11] for pH control at neutralization point by imposing it in fuzzy logic system. Their work focus on generalisation of controller for any waste water control conditions with satisfactory performance. However, it is not easy to build an effective fuzzy inference for multiple pH regions.

The study is to improve the performance of a conventional PID controller by integrating the fuzzy logic system in control loop. The novelty of study is on integrating the optimised Sugenno's fuzzy output with conventional PID controller to control the pH titration from pH 3 to pH 10. The work focus on the segment of fuzzy output function which is developed from heuristic data from open loop analysis.

II. Methodology

A model of the Ordinary Differential Equation process has been formulated and identified for the simulation work. An open-loop and simple close-loop tests are being simulated to obtain data and test for the sensitivity of pH model and fuzzy logic controller respectively. The pH model are used to design a control system and to conduct an analysis of controller performance. Next, the performance is compared and the best controller is chosen.

Hybrid control system is a combination of two or more than two controller in the control system. In this study, a combination of PID controller and Fuzzy logic controller is used for the control system.

A. Process Modeling

The process modeling is used for testing the model sensitivity at different manipulated variable. The flow of alkali or base is selected as manipulated input with several variant of flow rate. The pH dynamics is observed and recorded as open loop dataset. A following model can be obtained from [12, 13]:

$$-x_A + 10^{-p} - 10^{p \quad -1} + \frac{x_S}{1+1^{\ p \quad +p \quad -1}} = 0 \qquad \text{Eq. 1}$$

$$V\frac{d\ \ _A}{d} = F_A C_A - (F_A + F_S)x_A \qquad \text{Eq. 2}$$

$$V\frac{d\ \ _S}{d} = F_S C_S - (F_A + F_S)x_S \qquad \text{Eq. 3}$$

$$\iota \frac{d \quad ^{*}}{d} = p \quad - p \quad ^{*} ; \; p \quad = -l(\;_{1} k \qquad \text{Eq. 4}$$

Where x_S is ion concentration of base, x_A is ion concentration of acid, F_A is flow rate of acid, F_S is flow rate of base, C_A is concentration of acid, C_S is concentration of base, ι is time constant and the dissociation constant for water and base is $k_W = 10^{-14}$ mol^2 L^{-2} and$k_S = 5.7143 \times 10^{-9}$ mol L^{-1} respectively.

B. *Hybrid PID-Fuzzy Controller Design*

The control system is to ensure the pH level is maintained at certain desired value. In actual plant, the process are nonlinear, imprecisely known and multivariable with many interactions [6]. The fuzzy logic controller with Takagi-Sugeno fuzzy inference system has been chosen in this study. A single input and single output architecture has been selected for the fuzzy logic system to segment the PID controller output. The input, *pH* consist of 6 membership bell-shape functions has been designed (refer to Fig. 1). While, constant output, θ (as in Table 1) of membership has been optimized by trial and error method with fitness objective function (Eq. 5) of root mean square of error (RMSE).

$$J(R \quad) = \sqrt{\frac{1}{n}\sum_{i=1}^{N}\left(Y_i - \hat{Y}_i\right)^2} \qquad \text{Eq. 5}$$

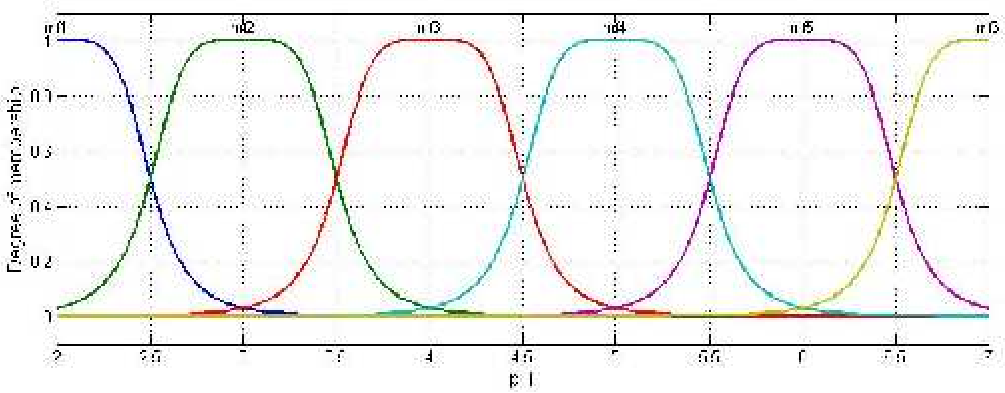

Fig. 1: Input membership function

Table 1: Sensitivity response of optimized output membership function.

Output (θ)	MF1	MF1	MF2	MF3	MF4	MF5
	5.0	4.8	4.6	4.4	4.2	4.0

The proposed controller is a combination of fuzzy logic and conventional PID controller. In control system loop (As in Fig. 2), the set point is compared with current pH value to obtain feedback error. Then the error is sent to the conventional PID controller to compute the manipulated variable and compensate the error over period of time. Simultaneously, the pH value has been fed to the Fuzzy logic to approximate the require value (θ) based on pH region. The value then is summed together with the PID controller output (U) and the adjusted controller output (manipulated variable) is effecting the process and control loop computation is continued.

The disturbance and the manipulated variable of the proposed controller are connected to the pH model (Controlled Plant). Fig. 2, show a negative feedback that has been used in this study.

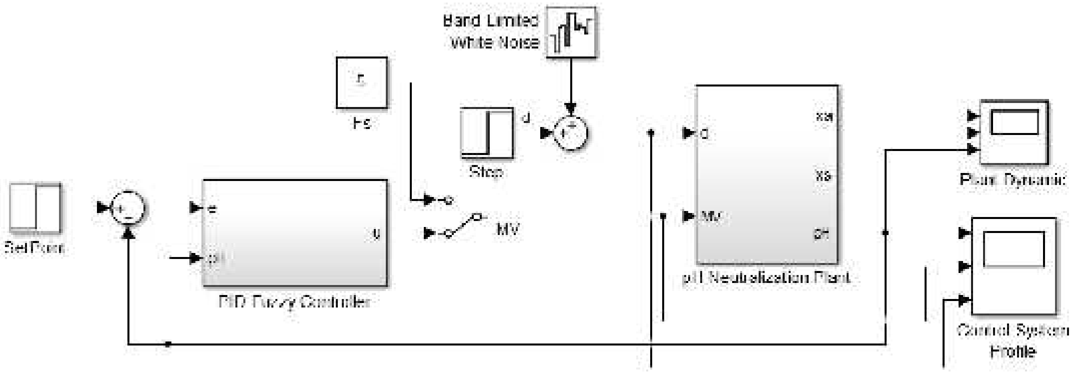

Fig. 2: Control system set up for hybrid controller of pH neutralization process

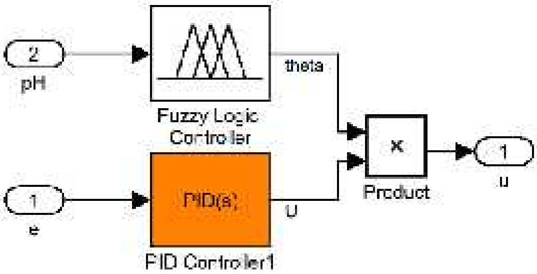

Fig. 3: The hybrid structure of fuzzy logic controller and PID controller

A comparison for servo (set-point tracking) and regulator (disturbance rejection) analysis has been carried out and the performance of controllers has been evaluated in the control system. It is to show the proposed controller can be used for nonlinear neutralization process system. The arrangement of the Hybrid Fuzzy-PID controller has be illustrated in Fig. 3.

III. RESULT AND DISCUSSION

The pH response as in Fig. 4 shows the PID control system and Fuzzy-PID control system are both able to reach desired pH set-point. The step change from pH 3 to pH 7 at time 20 seconds is introduced. The pH value is increased in response to the manipulated variable for both controllers. When the pH reaches the set point consistently, the manipulated variable will remain the same. However, the proposed controller reach the set-point faster than conventional controller. The process dynamic of Fuzzy-PID control system is consistently, faster and with no offset to the set points tracking of pH. Thus, Fuzzy-PID control system is better in set points tracking when comparing it to the conventional PID controller.

The intentional disturbance has been performed as a step change in load and it affect the plant dynamic and as the outcome, the pH value moves away from the desired set point. In Fig. 5, the set point is maintained at pH of 7 after 20 second. The regulatory control analysis is introduced for a disturbance step change (acid flow rate) from initial value of 1.5 to final value, 2 at change time of 60 seconds.

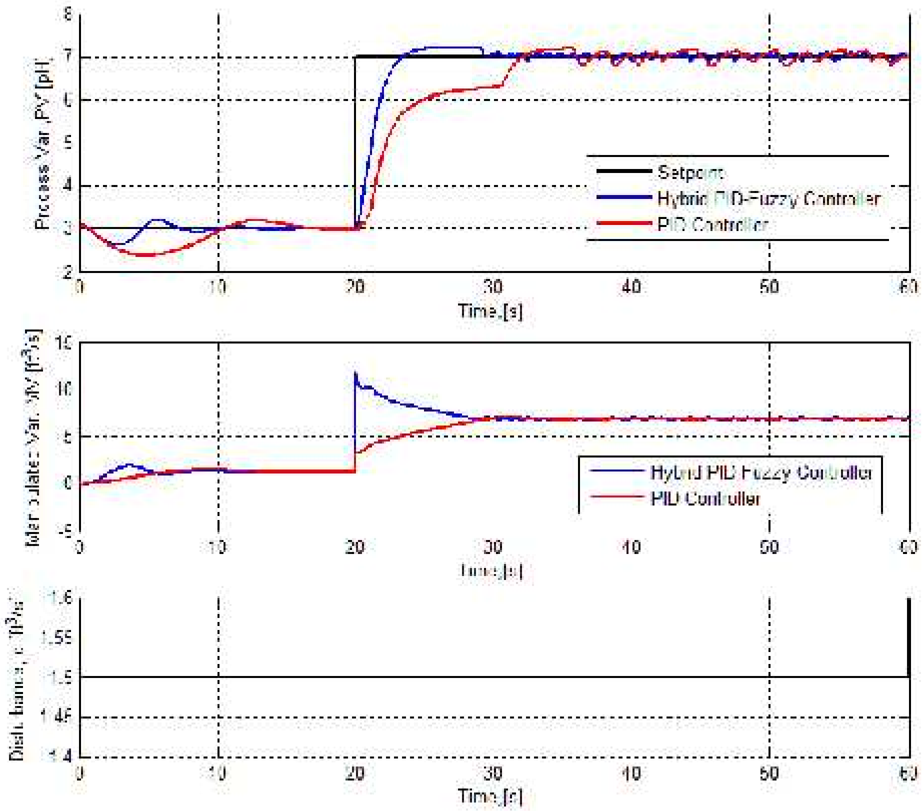

Fig. 4: Comparison between Fuzzy-PID control system and PID control system (Servo analysis)

From the Fig. 5, the main focused is on the rejection of disturbance which happens after time 60 seconds. The pH value suddenly decreases due to the disturbance that occurs and simultaneously, the manipulated variable value also increases to compensate the changes. Both controllers are capable to reject the disturbance and maintain the pH at set-point value. However, Fuzzy-PID control system is faster and no offset compared to the conventional PID controller. Therefore, the proposed controller is superior then conventional controller which can overcome the nonlinear pH value in neutralization process system.

The control loop response profile as in Fig. 6 shows multi servo control application. The set point start at pH 3, then pH 5, pH 7 and ended at pH 6. The proposed controller shows better control performance for all set-point values. As seen in Fig. 6, the manipulated value which is modified from adjusted variable (θ) is key factor in adapting the controller output at different pH region. The manipulated variable of conventional PID controller are not able to give necessary control action at different pH region due to process dynamic nonlinearity, whereas the proposed controller able to compensate the nonlinearity effect at every pH region.

The pH profile of Fuzzy-PID control system for all cases are consistent; fast response time and no offset. While, for the conventional PID controller, takes longer time to reach the set points. Therefore, the performance for the Fuzzy- PID control system is better compared to the conventional PID controller.

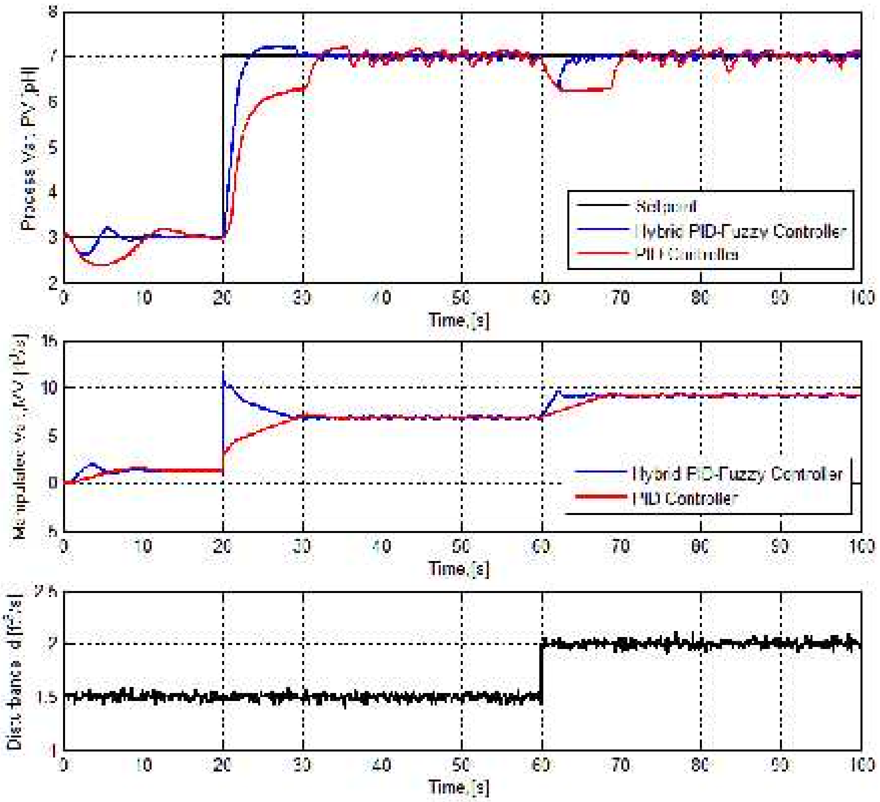

Fig. 5: Comparison between Fuzzy-PID control system and PID control system (Regulator Analysis)

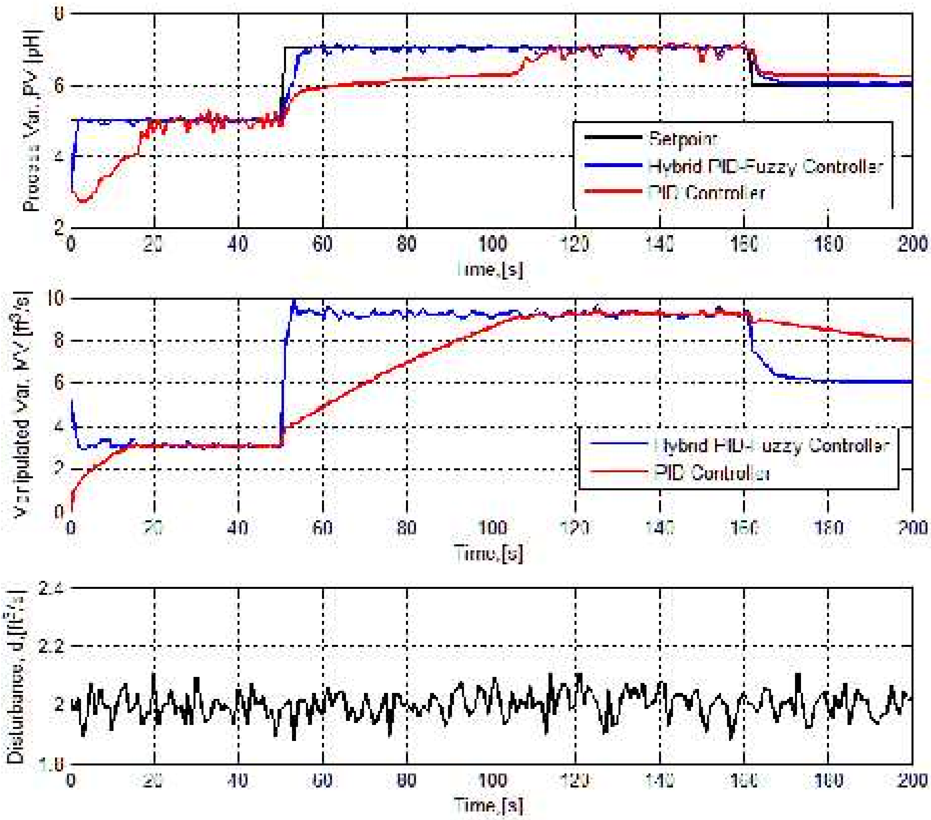

Fig. 6: Comparison between Fuzzy-PID control system and PID control system (Multiple Servo Analysis)

IV. CONCLUSION

This paper focus on the segmentation of fuzzy logic toward the improvement of conventional controller in pH neutralization process. The controller which is a combination of a fuzzy logic system with a conventional PID controller is proposed in this paper. The performance of the controller had been evaluated for servo and regulator cases. The result and the analysis of proposed controller had been compared with a conventional controller in the same control system setup. The result obtained show that the proposed controller is able to improve the conventional controller with significant results. The dynamic close loop profile of pH for the Fuzzy – PID control system is faster and with no offset to the several set points tracking when compared to the conventional PID controller. Therefore, the proposed controller is superior then conventional controller which can overcome the nonlinear pH value in neutralization process system.

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