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A Design of Fuzzy PID Controller Based on ARM7TDMI for Coupled-Tanks Process

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Abstract**:** This paper presents the design of Fuzzy PID controller based on ARM7TDMI for coupled-tanks process. The research is developed from previous studying of modified quadrupled-tanks process in the case of non-interacting second order process. The PID controller is designed by root locus technique, then it is improved a performance by combining with Fuzzy inference system for desired output response specification. Furthermore, PID Fuzzy inference system has been approximated into lookup table scheme for properly running on ARM7 embedded system. With the proposed method, the efficiency control algorithm can be performed on ARM7 platform that has a good performance and affordable costs. The experimental results have been shown that the design of Fuzzy PID embedded controller can achieve the performance specification requirement in level control.

Keywords: Fuzzy PID; ARM7TDMI; Coupled-Tanks Process

1. INTRODUCTION

Most of the controllers in operation today are PID controllers because of the fact that they have simple structures and admissible efficiency for industrial process. In PID control that can achieve the desired output response specification, PID controller has to be tuned by a proper technique, thus the various parameter tuning methods for conventional PID controllers have been proposed [1].

In our previous work, the design of PID controller using characteristic ratio assignment method for coupled-tanks process [2], PID controller for the modified quadruple-tanks process using root locus [3], and the design of PID controller for the modified quadruple-tanks process using inverted decoupling technique [4] have been proposed. The experimental results revealed that there are some limitations of control ranges due to non-linear process characteristic. Fuzzy logic control has been successfully applied to non-linear system because of their knowledge based non-linear structural characteristics, thus combination of Fuzzy logic and conventional PID control has been developed for increasing control performance in the various ways.

The intent of this study is to design Fuzzy logic proportional-integral-derivative (PID) control system so that a more improved system response performance in both the transient and steady states have been achieved as compared to the system response obtained by conventional PID control. In implementation with coupled-tanks process having non-linear characteristic, PID controller has been designed by root locus technique, then Design an equivalent fuzzy PID controller by configuring the fuzzy inference system so that it produces a linear control surface from inputs to output, determine scaling factors from the Kp, Ki, Kd gains used by the conventional PID controller, and adjust the fuzzy inference system to achieve nonlinear control surface. . Furthermore, PID Fuzzy inference system has been approximated into 2-D lookup table scheme for properly running on ARM7 embedded system. With the proposed method, the efficiency control algorithm can be performed on ARM7 platform that has a good performance and affordable costs. The experimental results have been illustrated that the design of Fuzzy PID embedded controller can achieve the performance specification requirement in level control.

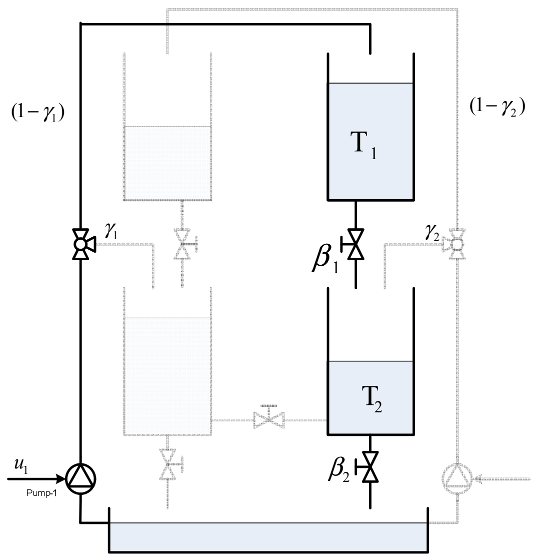

Fig. 1 The Coupled-Tanks Process

The remainder of the paper is organized as follows. In Section 2, we provide an overview of a coupled-tanks process. Then we summarize the Fuzzy PID controller design in section 3. In section4 we show how to implement a PID fuzzy control systems for a coupled-tanks process. Section 5 explains experiment and results. Finally, the conclusion is given in section 6.

2. COUPLED-TANKS PROCESS

Consider the coupled-tanks one-input one-output process in fig.1. The target is to control the level in lower tank by the inlet water flow from pumps 1. The process inputs are $u_1(t)$ (input voltage to pumps) and the outputs are $h_2(t)$ water level in tank 2.

The nonlinear plant equations can be obtained by mass balance equation and Bernoulli's law. After linearization process, we obtain the linearlized plant equations as (1)

$$\frac{dh_1(t)}{dt} = -\frac{\beta_1 a_1}{A}\sqrt{2gh_1(t)} + (1-\gamma_1)\frac{k_{p1}}{A}u_1(t) \qquad (1)$$
$$\frac{dh_2(t)}{dt} = -\frac{\beta_2 a_2}{A}\sqrt{2gh_2(t)} + \frac{\beta_1 a_1}{A}\sqrt{2g\left(h_1(t)\right)}$$

Where A is the cross section area of tank 1 and tank 2 (cm^2), a is the cross section area of outlet hole of tank 1, tank 2 and cross section area of jointed pipe between tank 1 and tank 2 (cm^2), β_1 is the valve ratio at the outlet of tank 1, β_2 is the valve ratio at the outlet of tank 2, $\bar{h}_1, \bar{h}_2$ are the steady-state water level of tank 1 and tank 2, g is the gravity (cm^2/s) and k_{p1} are the gain of pump 1 $(cm^3/V{\bullet}s)$.

From linearizing plant equations (1), we obtained plant transfer function as (2)

$$\frac{H_2(s)}{U_1(s)} = G(s) = \frac{T_2 k_{p1}/A}{(T_2 s+1)(T_1 s+1)} \qquad (2)$$

Where

$$T_1 = \frac{A}{\beta_1 a}\sqrt{\frac{2\bar{h}_1}{g}}, \quad T_2 = \frac{A}{\beta_2 a}\sqrt{\frac{2\bar{h}_2}{g}}$$

$\bar{h}_1, \bar{h}_2$ are the steady-state water level of tank 1 and tank 2, T_1 is the time constant of tank 1, T_2 is the time constant of tank 2.

3. FUZZY PID CONTROLLER

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The FIS output is the control action inferred from the fuzzy.

Nonlinear control surfaces can often be approximated by lookup tables to simplify the generated code and improve execution speed.

The fuzzy controller in this study is in the feedback loop and computes PID-like actions through fuzzy inference. The loop structure is displayed below in the Simulink diagram rules.

Designing a fuzzy PID controller involves configuring the fuzzy inference system and setting the four scaling factors: GE, GCE, GCU and GU.

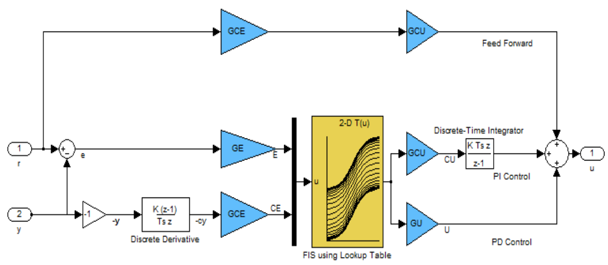

Fig. 2 Fuzzy PID Lookup Table Structure

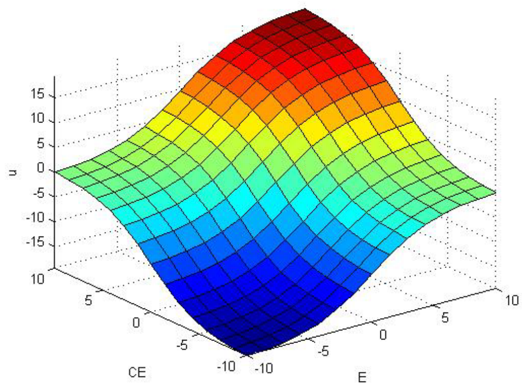

Fig. 3 Non-Linear Control Surface Data

The design steps

1. Design a conventional linear PID controller

The conventional PID controller is a discrete time PID controller designed by root locus technique. The controller gains are Kp, Ki and Kd.

2. Design an equivalent linear fuzzy PID controller

First, configure the fuzzy inference system so that it produces a linear control surface from inputs E and CE to output u. The FIS settings summarized below are based on design choices described in [2]:

- Use Mamdani style fuzzy inference system.
- Use algebraic product for AND connective.
- The ranges of both inputs are normalized to [-10 10].
- The input sets are triangular and cross neighbor sets at membership value of 0.5.
- The output range is [-20 20].
- Use singletons as output, determined by the sum of the peak positions of the input sets.
- Use the center of gravity method (COG) for defuzzification.

Construct fuzzy inference system:

Next, we determine scaling factors GE, GCE, GCU and GU from the Kp, Ki, Kd gains used by the conventional PID controller. By comparing the expressions of the traditional PID and the linear fuzzy PID, the variables are related as:

Kp = GCU * GCE + GU * GE (3)

Ki = GCU * GE (4)

Kd = GU * GCE (5)

Assume the maximum reference step is 1, whereby the maximum error e is 1. Since the input range of E is [-10 10], we first fix GE at 10. GCE, GCU and GCU are then solved from the above equations.

GE = 10 (6)
GCE = GE*(Kp-sqrt(Kp^2-4*Ki*Kd))/2/Ki (7)
GCU = Ki/GE (8)
GU = Kd/GCE (9)

3. Adjust the fuzzy inference system to achieve nonlinear control surface
4. Fine-tune the nonlinear fuzzy PID controller

4. SYSTEM IMPLEMENTATION

4.1 Hardware

Water level control system of coupled-tanks process shown in Fig. 4 and Fig. 5 consists of ARM7TDMI 32-bits embedded microcontroller board, DP transmitter, signal converter, pump driver board, pump and coupled-tanks process.

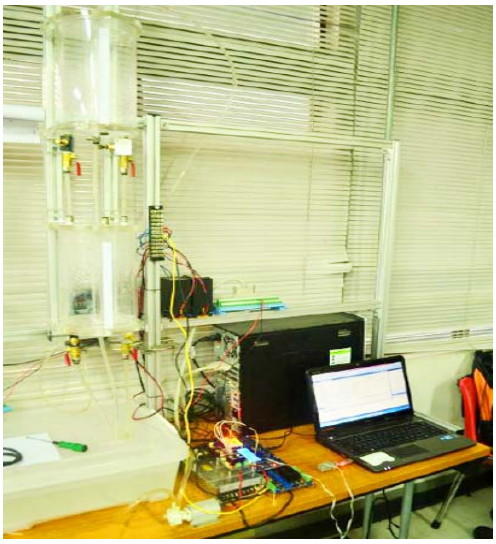

Fig. 4 Coupled-Tanks Process and Experimental System

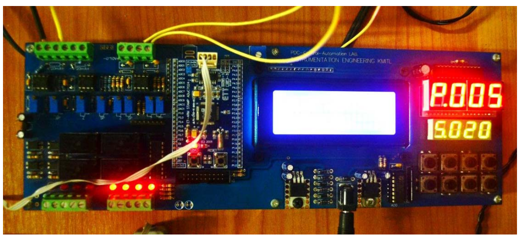

Fig. 5 Microcontroller ARM7TDMI Board

4.2 Software

Experimental Programs generated by C programing language and Keil uVision4 complier. The program is divided to 3 main parts as control algorithm, display and collecting data. The required set point and control function type can be defined from input terminal of ARM7TDMI microcontroller board. The response of control system can be demonstrated on LCD display and showing the graphical results on PC using user interface module developed by Viual Basis.Net.

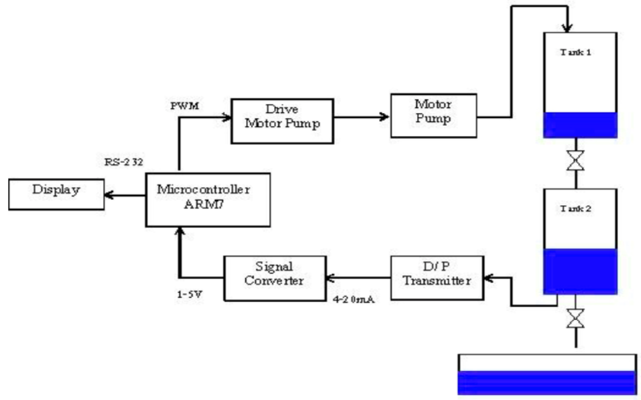

Fig. 6 Schematic of Coupled-Tanks Control System

5. EXPERIMENT AND RESULTS

We design a nonlinear fuzzy PID controller for a plant in Simulink. The plant is a single-input single-output system in discrete time and our design goal is simply to achieve good reference tracking performance. Parameters and operating point show detail in Table I and Table II. From this data formed by equation (2) then it is obtained the transfer function as.

$$G(s)=\frac{40.66}{(319.65s+1)(115.5s+1)} \tag{10}$$

Table 1 Parameters and operating point of coupled-tanks Process

$A_1,A_2:cm^2$	$a_1,a_2:cm^2$	β_1	β_2
169.56	01963	0.585	0.3517
$\bar{h}_1:cm$	$\bar{h}_2:cm$	$\bar{u};V$	$k_{p1}:cm^3/(V\cdot s)$
3	8.3	1	21.57

According to equation (31), design of PID controller based on root locus technique, then the parameters of PID controller are given by. Kd = 0.0239, Kp = 0.0197, Ki = 0.000403. The step response in fig.3, the overshoot is over 15.48 percent and settling time is at 15.2 min.

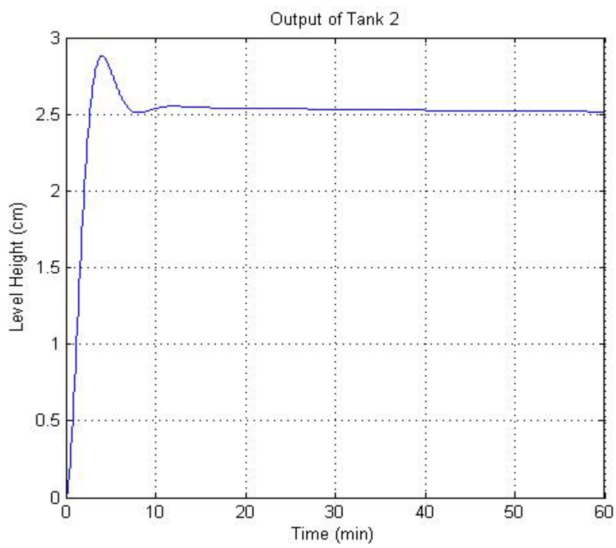

Fig. 7 Output Response of Tank2
(Conventional PID Control)

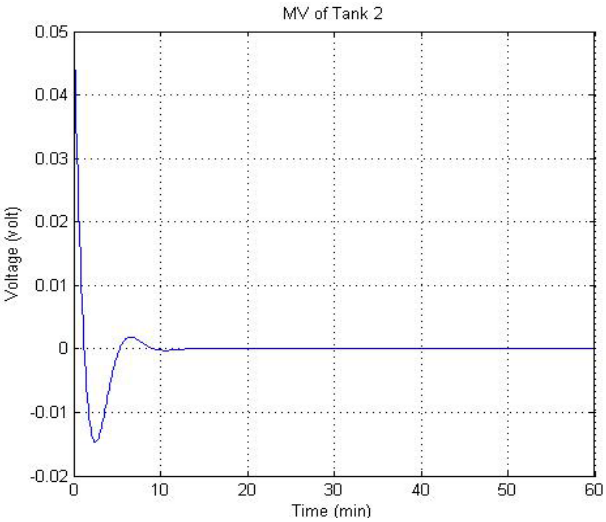

Fig. 8 Control Signal of Conventional PID Control)

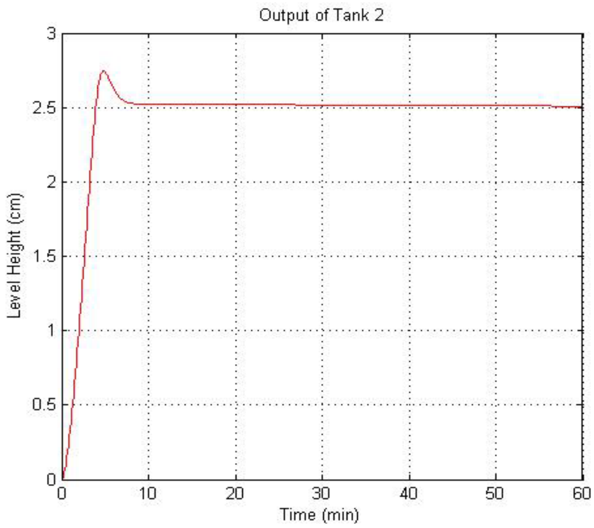

Fig. 9 Output Response of Tank2 (Fuzzy PID Control)

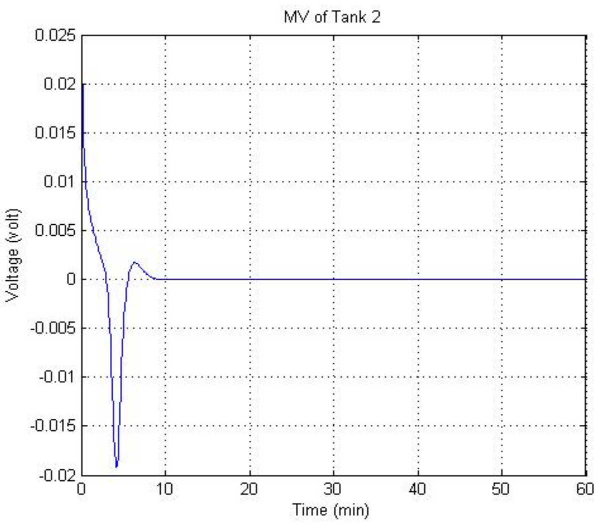

Fig. 10 Control Signal of Fuzzy PID Control

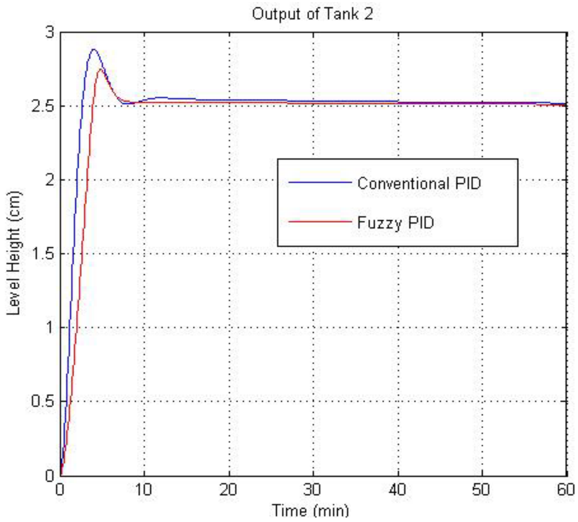

Fig. 11 Output Response of Tank2 (Fuzzy PID Compared with Conventional PID)

Table 2 Comparison of control performance

	Setting Time	Max P.O. %
Conventional PID	15.2 Min	15.48
Fuzzy PID	8.1 Min	9.64

6. CONCLUSION

The design of Fuzzy PID controller using root locus technique based on ARM7TDMI for coupled-tanks process has been proposed in this paper. From the experimental results, they have been shown that combining Fuzzy inference system to PID controller can properly be applied to non-interacting second order process. Furthermore, the Fuzzy lookup table scheme can properly be performed on ARM7 embedded system that has a good performance and affordable costs. The experimental results have been shown that the design of Fuzzy PID embedded controller can achieve the performance specification requirement in level control.

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