Decentralized Fuzzy Logic Controller for TITO Coupled-Tank Process

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Abstract: This paper presents implement in level control of a TITO coupled-tank process using decentralized fuzzy logic controller (DFLC) based on LabVIEW program. LabVIEW is a powerful graphical development environment for signal acquisition, measurement, analysis and data presentation. The decentralized fuzzy logic controller designed with PID control toolset on LabVIEW. Several experimental results are present to illustrate the effectiveness of the proposed method and compared it with PID controller.

Keywords: Decentralized, Fuzzy Logic, TITO Process, Coupled-Tank, LabVIEW

1. INTRODUCTION

Processes with only one output being control by a single manipulated variable are classify as single-input single-output (SISO) systems. For the process having more than one control loop can be called multi-input multi-output (MIMO) or multivariable process which very often found that in power plant, refinery process, chemical industries and many other fields [1],[2]. The control of these processes is more difficult than SISO processes. Because there is an interaction between other control loops of MIMO processes. Therefore the method used for SISO systems cannot use for control of MIMO systems effectively. The most common form or well-known form of MIMO system is a two-input two-output (TITO) system. Generally controller design for TITO process applies from two theory methods. First method is modern controller design which uses centralized controller to satisfy response specification but it still has some difficulty in starting control system. Second method is classical controller design which uses decentralized controller such as a simple PID controller but controller parameters is still complicate for evaluation. Many techniques have been present in the literature for the control of TITO system such as dominant pole placement [3], decentralized relay autotune method [4,5], decentralized decoupling method [6,7] are among them.

Recently, the fuzzy logic controller has been used in control system when the mathematical model of the interested process is vague of exhibits uncertainties. Fuzzy control has found promising applications for a wide variety of industrial systems, not only for SISO nonlinear systems but also for MIMO nonlinear systems. The main advantages of these fuzzy-logic-based control schemes lies in the fact that the developed controller can deal with increasingly complex systems and to implement controllers without precise knowledge of the model structure of underlying dynamic systems.

In this paper, we implement a decentralized fuzzy logic controller for TITO coupled-tank process that influences from and interaction between two tanks. The performance of its will compared with PID controller.

The rest of the paper organized as follows. In section 2, gives overview of TITO coupled-tank process. The design of decentralized fuzzy logic controller for TITO coupled-tank process is explained in Section 3. Section 4, explain an experimental setup. Then experimental results show in section 5. Finally, conclusions are giving in section 6.

2. TITO COUPLED-TANK PROCESS

Consider the two-input two-output coupled-tank process in Fig.1. The target is to control the level in two tanks with two pumps. The process input are $u_1(t)$, $u_2(t)$ (input voltage to the pumps) and the outputs are $h_1(t)$, $h_2(t)$ water level in tank 1 and tank 2 respectively).

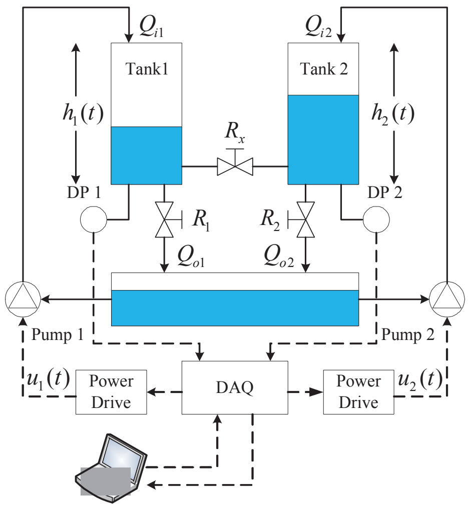

Fig1. The TITO couple-tank process

The linearised dynamics for the process [6] is given as:

$$\begin{aligned}\frac{dh_1(t)}{dt} &= \frac{k_1}{A}U_1(t) - \frac{\beta_1 a}{A}\sqrt{\frac{g}{2\bar{h}_1}}H_1(t) \\ &\quad + \frac{\beta_x a}{A}\sqrt{\frac{g}{2\left|\bar{h}_2-\bar{h}_1\right|}}\left[H_2(t)-H_1(t)\right] \\ \frac{dh_2(t)}{dt} &= \frac{k_2}{A}U_2(t) - \frac{\beta_2 a}{A}\sqrt{\frac{g}{2\bar{h}_2}}H_2(t) \\ &\quad - \frac{\beta_x a}{A}\sqrt{\frac{g}{2\left|\bar{h}_2-\bar{h}_1\right|}}\left[H_2(t)-H_1(t)\right]\end{aligned} \tag{1}$$

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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 and tank 2 and cross section area of jointed pipe between tank 1 and tank 2 (cm^2), β_1 and β_2 are the valve ratio at the outlet of tank 1 and tank 2 , β_x is the valve ratio between tank 1 and tank 2, $\bar{h}_1$ and $\bar{h}_2$ are the steady-state water level of tank 1 and tank 2, g is the gravity (cm^2/s) and (k_1), (k_2) are the gain of pump 1 and pump 2 (cm^3/V)

From the linearised equations (1) can be transformed to the transfer matrix equation as (2)

$$\begin{bmatrix} H_1(s) \\ H_2(s) \end{bmatrix} = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \begin{bmatrix} U_1(s) \\ U_2(s) \end{bmatrix} \tag{2}$$

Where transfer matrix $G_{ij}(s)$ has the value as following

$$\begin{aligned}
G_{11}(s) &= \frac{\frac{k_1}{A}\left(s + \frac{T_x + T_2}{T_2 T_x}\right)}{s^2 + \left(\frac{T_1 T_x + T_2 T_x + 2T_1 T_2}{T_1 T_2 T_x}\right) + \left(\frac{1}{T_1 T_2} + \frac{1}{T_1 T_x} + \frac{1}{T_2 T_x}\right)} \\
G_{12}(s) &= \frac{\frac{k_2}{A}}{s^2 + \left(\frac{T_1 T_x + T_2 T_x + 2T_1 T_2}{T_1 T_2 T_x}\right) + \left(\frac{1}{T_1 T_2} + \frac{1}{T_1 T_x} + \frac{1}{T_2 T_x}\right)} \\
G_{21}(s) &= \frac{\frac{k_1}{A}}{s^2 + \left(\frac{T_1 T_x + T_2 T_x + 2T_1 T_2}{T_1 T_2 T_x}\right) + \left(\frac{1}{T_1 T_2} + \frac{1}{T_1 T_x} + \frac{1}{T_2 T_x}\right)} \\
G_{22}(s) &= \frac{\frac{k_2}{A}\left(s + \frac{T_x + T_1}{T_1 T_x}\right)}{s^2 + \left(\frac{T_1 T_x + T_2 T_x + 2T_1 T_2}{T_1 T_2 T_x}\right) + \left(\frac{1}{T_1 T_2} + \frac{1}{T_1 T_x} + \frac{1}{T_2 T_x}\right)}
\end{aligned} \tag{3}$$

$$T_1 = \frac{A}{\beta_1 a}\sqrt{\frac{2\bar{h}_1}{g}}, \quad T_2 = \frac{A}{\beta_2 a}\sqrt{\frac{2\bar{h}_2}{g}}, \quad T_x = \frac{A}{\beta_x a}\sqrt{\frac{2\left|\bar{h}_1 - \bar{h}_2\right|}{g}}$$

T_1, T_2 are the time constant of tank 1 and tank 2, T_x *i*s the time constant between tank 1 and tank 2.

3. DECENTRALIZED FUZZY CONTROLLER (DFLC) DESIGN

Fuzzy logic is derived from fuzzy set theory introduced by Zadeh in 1965.[8] In fuzzy set theory, the transition between membership and non-membership can be gradual .Therefore boundaries of fuzzy sets can be and ambiguous, making it useful for approximate system. Combining multi valued logic, probability theory, and knowledge base, fuzzy logic control (FLC) is based on the simulation of human thinking by incorporating the imprecision inherent in all physical systems. Fuzzy logic controller is an attractive choice when mathematical formulations are not possible [9,10].

The decentralized fuzzy control structure includes two fuzzy SISO controllers. In the proposed control method for the TITO coupled-tank process, two fuzzy logic controllers used separately for controlling the level outputs. The structure is shown in Fig.2.

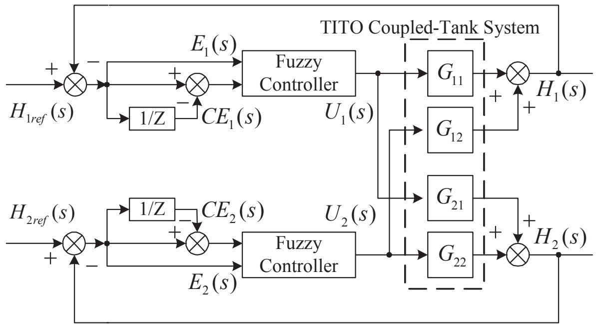


Fig.2 The configuration of decentralized fuzzy logic controller with TITO system

The fuzzy logic controller based on level in two tanks. In this work the error and change in error of level outputs ($h_1(t)$ and $h_2(t)$) are taken as inputs and the pump voltages ($u_1(t)$ and $u_2(t)$) are the controller outputs. The membership of error input is converted in to seven linguistic values namely NB, NM, NS, ZE, PS, PM and PB while membership of change of error input is converted in to three linguistic values namely N, ZE and P. Similarly membership of controller output is converted same as membership of error input. Fig.3, 4 and 5 shows the fuzzy sets and corresponding triangular membership of error input, change of error input and output membership functions respectively.

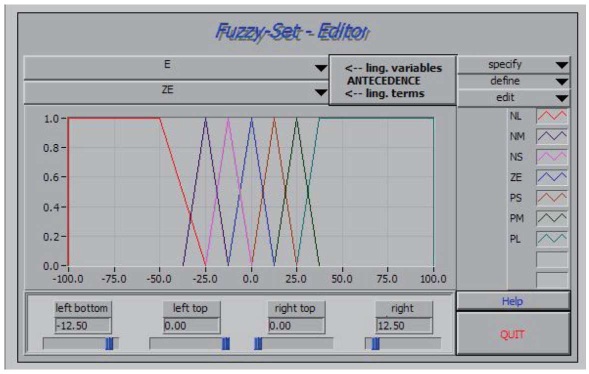


Fig.3 Error input membership functions

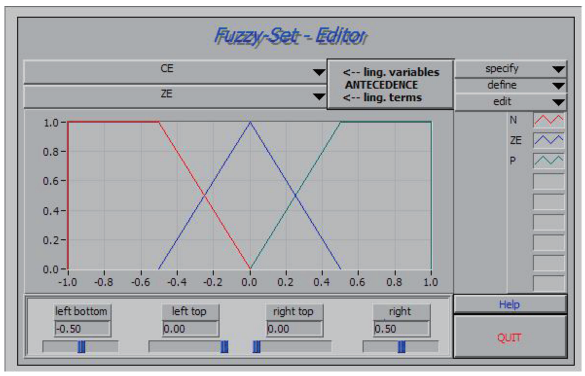


Fig.4 Change of error input membership functions

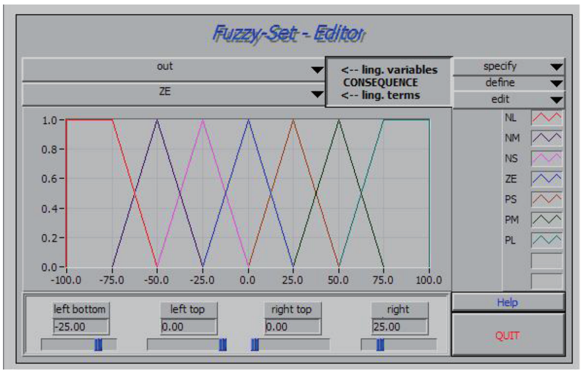


Fig.5 Output membership functions

The control rules for the fuzzy logic controller are shows in Table.1. The output of fuzzy controller obtained by using center of gravity (COG) method of defuzzification module.

Table. 1 Control rules of fuzzy logic controller

E CE	N	ZE	P
NL	NB	NB	NM
NM	NM	NM	NS
NS	NM	NS	NS
ZE	NS	ZE	PS
PS	ZE	PS	PS
PM	PS	PM	PM
PL	PM	PB	PB

4. EXPERIMENTAL SETUP

In this section, the experimental setup consists of TITO coupled-tank process, DAQ card and software which have the details as following

4.1 TITO Coupled-Tank Process Apparatus

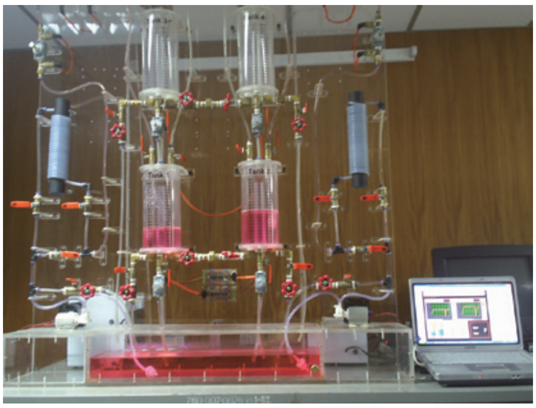


Fig. 6 The experimental setup

Coupled-Tanks Process in Fig.6 consist of 66.25 (cm^2) cross section area of tank, 20 (cm) height tanks which have their own 0.1963 (cm^2) cross section area of outlet valve and interconnected valve between two tanks, each tank has gear pump which gives 2,200 ml / min . For a level measurement apparatus, we use two DP transmitters which their output 4-20 mA varies by 0-100 % of level range.

4.2 Controller Design

According to Fig.6, The water level signals from DP transmitters are sent to computer via DAQ card. The controllers which run by LabVIEW software compare the measurement signals to the set-point and calculate the control signals to power drive via DAQ card for succeeding in water level height control.

4.2.1 DAQ Card

The DAQ card for interface in between TITO process and laptop is shown in Fig. 7. We use NI USB-6008 which has 8 analog input (12-bit, 10KS/s), 2 analog output (12-bit, 150S/s), 12 digital input-output and 32bit counter


Fig. 7 NI USB-6008 DAQ card

4.2.2 LabVIEW Software

The experimental fuzzy logic controller software done by LabVIEW version 8.2. The front panel and block diagram of LabVIEW software shown in Fig. 8 and Fig. 9 respectively.

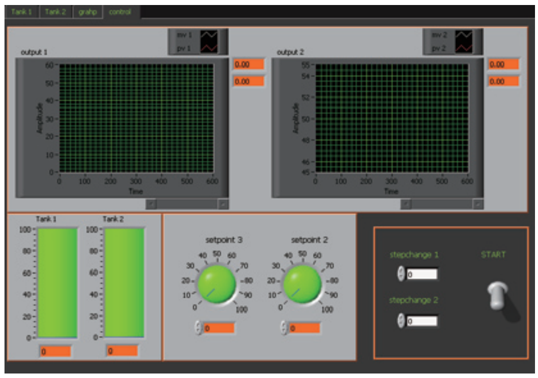


Fig. 8 Front panel of LabVIEW software

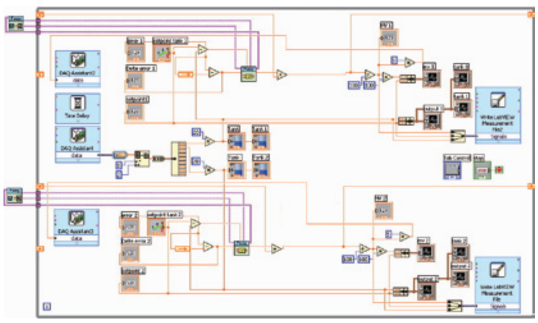


Fig. 9 Block diagram of LabVIEW software

5. EXPERIMENTAL RESULTS

In this section, the experimental results of decentralized fuzzy logic controller (DFLC) can be show in two parts. First is the step response due to comparison between proposed method and PID controller. Finally, the illustration of interaction effect between control loops due to set-point changed.

5.1 Comparison between DFLC and PID Controller

In this part, the performance comparison between DFLC and decentralized PID controller show that. In this case, parameter of PID controller for loop 1 and loop 2 obtained by Ziegler-Nichols reaction curve method. Also parameter of PID controller are K_p = 14.91, T_i = 0.34 and T_d = 0.085 respectively.

The step responses from 0 to 30% of DFLC compare with decentralized PID controller are show in Fig.10. It is obvious that DFLC produces a step response without an overshoot, fast settling time when comparison with decentralized PID controller. Table 3 represents the performance values of the control system in Fig.10.

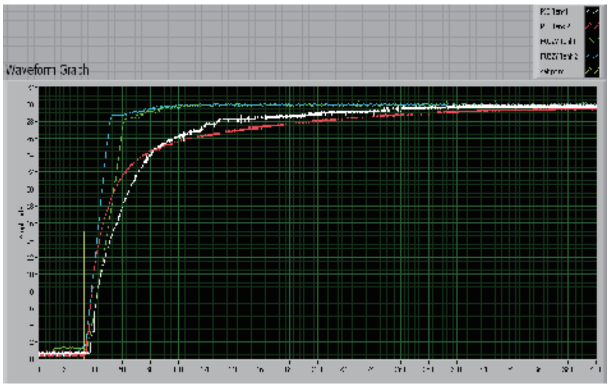


Fig.10 Step response for comparison between DFLC and decentralized PID controller

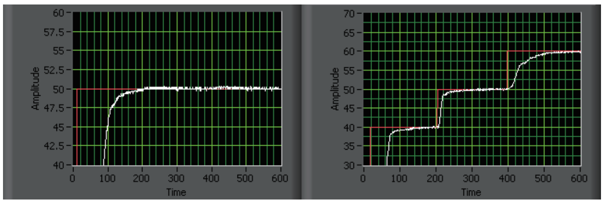
Table 3 Performance Values of the Time Response Curve Shown in Fig.10

Controller	Settling time		Max. overshoot	
	Loop 1	Loop 2	Loop 1	Loop 2
Decentralized FLC	60 s	60 s	0 %	0 %
Decentralized PID	280 s	340 s	0 %	0 %

5.2 Interaction Effect between Control Loops

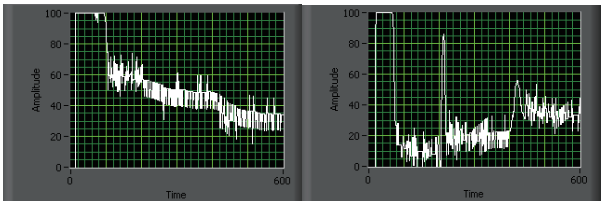
This part the illustration of interaction effect between control loops due to set-point changed of control system can be shown in four cases respectively.

First case is the response to a step input increase from 40% to 50% and 50% to 60% for loop2 while set-point of loop1 unchanged at 50%. The response results and control signal of DFLC are show as Fig.11 and Fig.12. From Fig.11 shows that the interaction effect of loop1 due to set-point changed of loop2 less than 1%. For step response of loop 2 at t=200s and t=400s without an overshoot and obtained settling time 60 second and 120 second respectively.



(a) (b)

Fig.11 Time response of control system
(a) loop1, (b) loop2



(b)

Fig.12 Control signal of DFLC
(a) loop1, (b) loop2

Next, same as first case but step input increase for loop1 while set-point of loop2 unchanged. The response results and control signal of DFLC are show as Fig.13 and Fig.14. From Fig.13 shows that the interaction effect of loop2 due to set-point changed of loop1 less than 1%. For step response of loop 1 at t=200s and t=400s without an overshoot and obtained settling time 80 second and 100 second respectively.

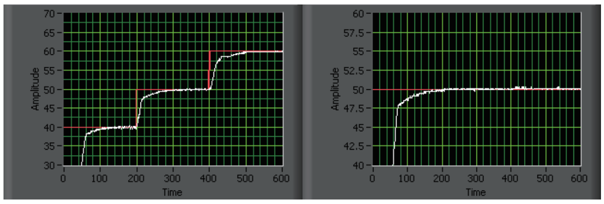


Fig.13 Time response of control system
(a) loop1, (b) loop2

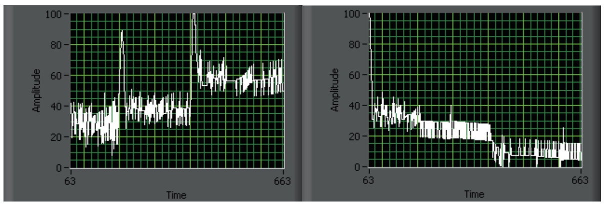


Fig.14 Control signal of DFLC
(a) loop1, (b) loop2

Third case is the response to a step input decrease from 50% to 40% and 40% to 30% for loop2 while set-point of loop 1 unchanged at 50%. The response results and control signal of DFLC are show as Fig.15 and Fig.16. From Fig.15 shows that the interaction effect of loop1 due to set-point changed of loop2 less than 1%. For step response of loop 1 at t=200s and t=400s without an overshoot and obtained settling time 100 second and 130 second respectively.

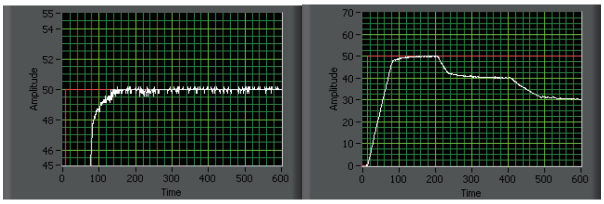


Fig.15 Time response of control system
(a) loop1, (b) loop2

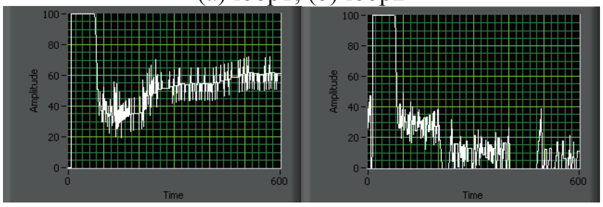


Fig.16 Control signal of DFLC
(a) loop1, (b) loop2

Finally same as third case but step input decrease for loop1 while set-point of loop2 unchanged. The response results and control signal of DFLC are show as Fig.17 and Fig.18. From Fig.17 shows that the interaction effect of loop2 due to set-point changed of loop1 less than 1%. For step response of loop 1 at t=200s and t=400s without an overshoot and obtained settling time 80 second and 120 second respectively.

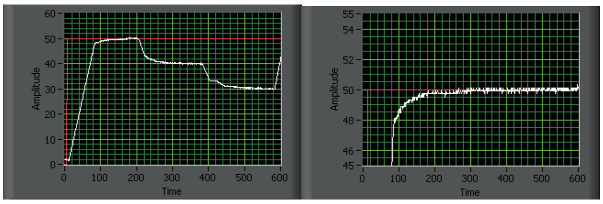


Fig.17 Time response of control system
(a) loop1, (b) loop2

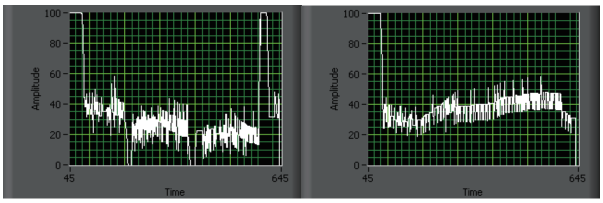


Fig.18 Control signal of DFLC
(a) loop1, (b) loop2

6. CONCLUSION

This paper proposed a decentralized fuzzy logic controller (DFLC) for TITO coupled-tank process. The control system is tested with LabVIEW program. The results of experiment on the real plant demonstrate that the proposed method has a good set-point tracking without any offset with reasonable settling time. Moreover, the proposed method can minimize the influences of interaction effect between control loops.

REFERENCES

[1] J.M. Maciejowski, *Multivariable Feedback Design*, Addison-Wesley, 1989

[2] S. Skogestad and I. Plstelthwaite., *Multivariable Feedback Control Analysis and Design*, John Wiley & Sons, Chichester, 1996

[3] Yu Zhang, Ing-Guo Wang; and K.J. Astrom, “Dominant pole placement for multi-loop control systems”, *Proc. Of American control Conf.*, Vol.3, pp. 1965-1969,2000

[4] Z.J. Palmor, Y. Halevi and N. Krasney, “Automatic tuning of decentralized PID controllers for TITO processes”, *Automatica*, Vol.31, No.7, pp. 1001-1010, 1995

[5] Q.C. Wang, B. Zou, T.H. Lee and Q. Bi “Auto tuning of multivariable PID controllers from decentralized relay feedback”, *Automatica,* Vol.33, No.3, pp. 319-330, 1997

[6] Arjin Numsomran, Theerachai Wongkhum, Tianchai Suksri, Phongchai Nilas and Jutarut Chaoraingern, “Design of Decoupled Controller for TITO System using Characteristic Ratio Assignment”, *Proceedings of the International Conference on Control, Automation and Systems (ICCAS)*, pp. 957-962, Oct.17-20, 2007, COEX, Seoul, Korea

[7] Arjin Numsomran, Tianchai Suksri and Maitree Thumma, “Design of 2-DOF PI Controller with Decoupling for Coupled-Tank Process”, *Proceedings of the International Conference on Control, Automation and Systems (ICCAS)*, pp. 339-344, Oct.17-20, 2007, COEX, Seoul, Korea

[8] L. A. Zadeh, “Fuzzy Sets”, *information and Control*, Vol.8, pp 338-353, 1965

[9] J. J. Buckley and H. Ying., “Fuzzy controller theory: Limit theorems for linear fuzzy control rules”, *Automatica*, Vol. 25, No. 3, pp.469–472, 1989.

[10]D. Driankov, H. Hellendoorn, and M. Reinfrank., *An Introduction to FuzzyControl*, Springer-Verlag, New York, 1993.