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Modeling and Development of Decentralized PI Controller for Nonlinear System

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Abstract: The main of this project is to control the nonlinear system (Quadruple tank process). For better control to achieve modeling of quadruple tank is required. The modeling is obtained by linearization technique and Jacobian matrix. The designing of controller is a challenging task. The system response is achieved using Decentralized PI (Proportional Integral) controller. The system response for two control paring configuration is simulated using MATLAB.

Keywords: *Quadruple Tank Process, Modeling, Decentalized PI Controller, Ideal Decoupler, Control Paring Configuration.*

I. INTRODUCTION

The primary objective of process control is to maintain the process at the desirable operating condition safely and efficiently, while satisfying the environmental and product quality requirement. In process control various parameters (level, flow, pressure, temperature) need to be controlled. The level is one of the most important parameter required to be considered, because it indirectly affects remaining parameters. The main idea of this work is to develop mathematical model and control the process level using Conventional PI Controller. The MIMO system response for two control paring is obtained.

II. DETAILS EXPERIMENTAL

A. Quadruple Tank Process

The Quadruple tank is a laboratory process with four interconnected tanks and two pumps. The process inputs are u1 and u2 (input voltages to pumps) and the outputs are y1 and y2 (voltages from level measurement devices). The target is to control the level of the lower two tanks with inlet flow rates. The output of each pump is split into two using a three-way valve.

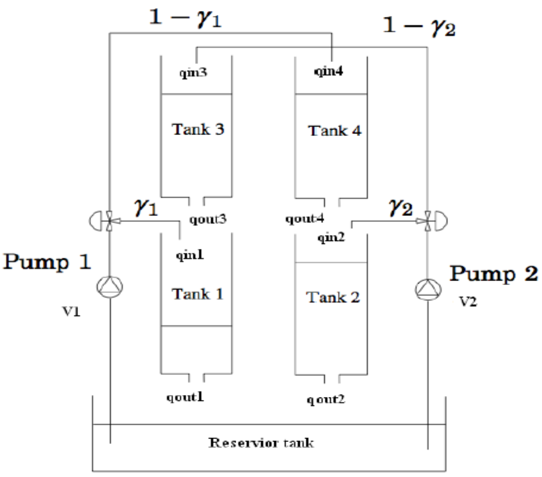

Figure1: Schematic Diagram of Quadruple Tank Process

Pump 1 is shared by tank 1 and tank 3, while pump 2 is shared by tank 2 and tank 4. Thus each pump output goes to two tanks, one lower and another upper diagonal tank and the flow to these tanks are controlled by the position of the valve represented as Ɣ. The schematic diagram of a quadruple tank process(MIMO-Multi Input Multi Output) is shown in **Figure1**.

B. Modeling

The Modeling of a process is necessary to investigate how the behavior of a process changes with time under influence of changes in the external disturbances and manipulated variables and to consequently design an appropriate controller. In such case a representation of the process is required in order to study its dynamic behavior. This representation is usually given in terms of a set of mathematical equations whose solution gives the dynamic behavior of the process. For each tank i=1...4, the mathematical modeling is done by considering mass balance equation and Bernoulli's law. The differential equation of quadruple tank is obtained as

$$\frac{dh1}{dt} = \left(\frac{\gamma 1k1v1}{A1}\right) + \left(\frac{a3\sqrt{2gh3}}{A1}\right) - \left(\frac{a1\sqrt{2gh1}}{A1}\right)$$

$$\frac{dh2}{dt} = \left(\frac{\gamma 2k2v2}{A2}\right) + \left(\frac{a4\sqrt{2gh4}}{A2}\right) - \left(\frac{a2\sqrt{2gh2}}{A2}\right)$$

$$\frac{dh3}{dt} = \left(\frac{(1-\gamma 2)k2v2}{A3}\right) - \left(\frac{a3\sqrt{2gh3}}{A3}\right)$$

$$\frac{dh4}{dt} = \left(\frac{(1-\gamma 1)k1v1}{A4}\right) - \left(\frac{a4\sqrt{2gh4}}{A4}\right)$$

Where

A1,A2,A3,A4-c.s area of the tank1,2,3,4

h1,h2,h3,h4-height of water in tank1,2,3,4

v1,v2-velocity of flow through pump1and2

k1,k2-pump constant

γ1,γ2-valve ratio

a1,a2,a3,a4-area of outlet pipe of tank1,2,3,4

g-acceleration due to gravity

By using Jacobian Matrix, the nonlinear differential is linearized into state space model. The Jacobian matrix is represented as

$$A=\frac{\delta f}{\delta h}(\eta,\upsilon)=\begin{pmatrix} \delta f1/\delta h1 & \delta f1/\delta h2 & \delta f1/\delta h3 & \delta f1/\delta h4 \\ \delta f2/\delta h1 & \delta f2/\delta h2 & \delta f2/\delta h3 & \delta f2/\delta h4 \\ \delta f3/\delta h1 & \delta f3/\delta h2 & \delta f3/\delta h3 & \delta f3/\delta h4 \\ \delta f4/\delta h1 & \delta f4/\delta h2 & \delta f4/\delta h3 & \delta f4/\delta h4 \end{pmatrix}$$

$$B=\frac{\delta f}{\delta u}(h,u)=\begin{pmatrix}\delta f1/\delta u1 & \delta f1/\delta u2\\ \delta f2/\delta u1 & \delta f2/\delta u2\\ \delta f3/\delta u1 & \delta f2/\delta u2\\ \delta f4/\delta u1 & \delta f2/\delta u2\end{pmatrix}$$

The state space model of process is determined using Jacobian matrix and coefficient of process state space is established from **Table1** below.

Table 1: Parameters Specification

Parameters	**Value**
A1=A2=A3=A4	63.585cm/2
a1=a2	1.246cm/2
Operating point of h1 &h2	12.4 &12.7 cm
Operating point of h3 &h4	1.8 & 1.4 cm
k1= k2	3.3cm/3/vs
γ1 & γ2	0.7 &0.6

$$A=\begin{pmatrix}-0.1232 & 0 & 0.2038 & 0\\ 0 & -0.3668 & 0 & 0.2310\\ 0 & 0 & -0.2038 & 0\\ 0 & 0 & 0 & -0.2310\end{pmatrix}$$

$$B=\begin{pmatrix}0.0367 & 0\\ 0 & 0.0316\\ 0 & 0.0211\\ 0.0157 & 0\end{pmatrix}$$

$$C=\begin{pmatrix}0.5 & 0 & 0 & 0\\ 0 & 0.5 & 0 & 0\end{pmatrix}$$

$$D=\begin{pmatrix}0 & 0\\ 0 & 0\end{pmatrix}$$

The transfer function matrix is determined from state space model. Below matrix represents the process transfer function matrix

$$G_p(s)=\begin{pmatrix}G_{11}(s) & G_{12}(s)\\ G_{21}(s) & G_{22}(s)\end{pmatrix}=$$

$$\begin{pmatrix}0.0184/(s+0.1232) & 0.0022/(s+0.1232)(s+0.2038)\\ 0.0018/(s+0.2310)(s+0.3668) & 0.0158/(s+0.3668)\end{pmatrix}$$

From the obtained process transfer function matrix, the interactive process response is shown in below **Figure2.**

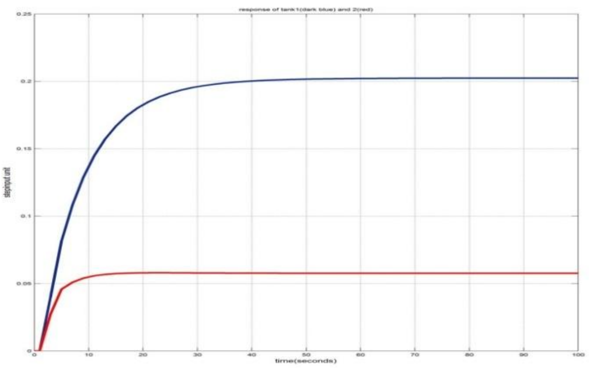

Figure 2: Interactive Process response of tank1 and tank 2

III. RESULTS AND DISCUSSION

A. Decentralized PI Controller Design

The quadruple process is a MIMO system which has multi loops. When a variation occurs in any inputs, the system becomes nonlinear because of multi loop interactions. In order to eliminate the process interaction Decentralized controller is used. The interaction is eliminated by using ideal decoupling control which is similar to the conventional feedback controller. The block diagram of decoupling control and process is shown in **Figure3.**

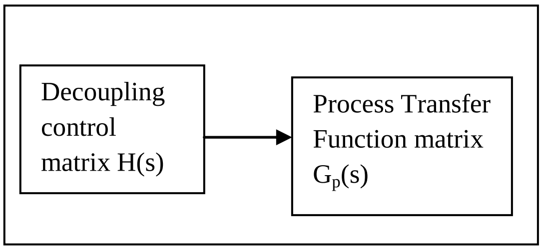

Figure 3: Block Diagram of Process with Decoupling Control.

A. Decoupling Control

For a two manipulated variable and two controlled variable, there will be two different configurations available (n!). When input1 is subjected to change, the output of tank1 changes and simultaneously tank2 output is changed because of $G_{21}(s)$ and when input2 is altered, then the output of both tank1 and 2 are changed because of $G_{12}(s)$. For a 2*2 process transfer function, the Decoupling Control H(s) is obtained from

$$H(s)=\begin{pmatrix}1 & -G12/G11\\ -G21/G22 & 1\end{pmatrix}$$

The PI Controller value are tabulated

Table 2: PI Controller Gain Value.

Parameter	**Controller1**	**Controller2**
Proportional gain	13.1286	18.3467
Integral gain	3.4624	12.8720

The process response for two control paring is achieved with the same controller values is shown.

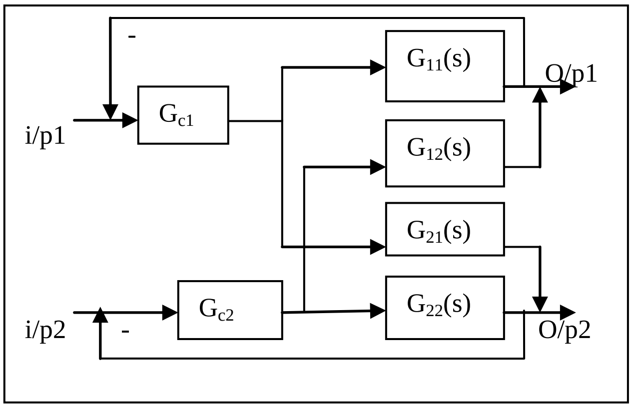

Figure 4: 1-1/2-2 Control Paring Block Diagram

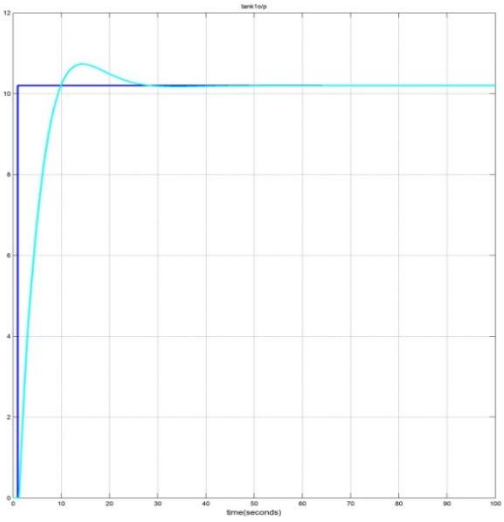

Figure 5: 1-1/2-2 Control Paring O/p response of Tank1

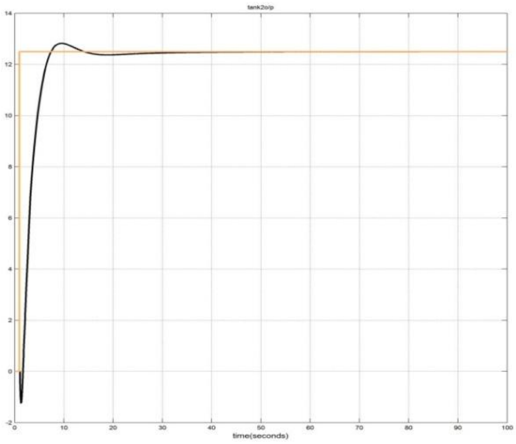

Figure 6 1-1/2-2 Control Paring O/p response of Tank2

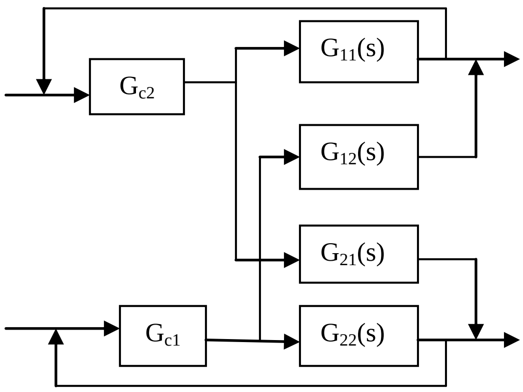

Figure 7: 1-2/2-1 Control Paring Block Diagram

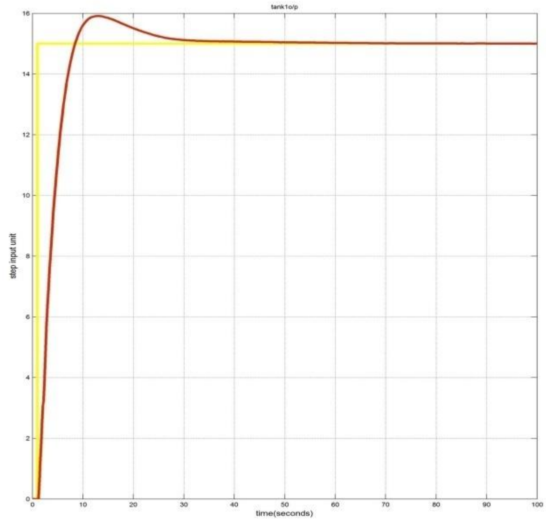

Figure 8: 1-2/2-1 Control Paring O/p response of Tank1

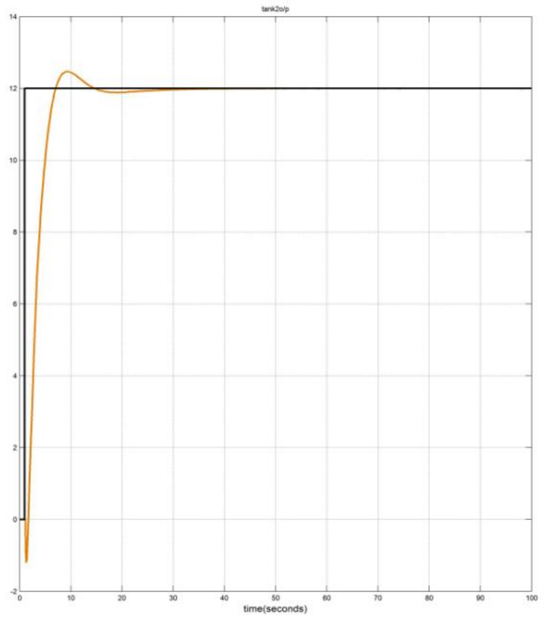

Figure 9: 1-2/2-1 Control Paring O/p response of Tank2

CONCLUSIONS

The output response of tank1 and 2 for the quadruple process is tuned using Decentralized PI Controller. The two control paring configuration response is also shown. We infer that

1. Loop interactions are eliminated.
2. The process reaches desired step input value.

Acknowledgments

The transient response for two control paring configuration are tabulated below.

Table 3: Comparison of Two Control Paring Configurations.

Transient Response Parameters.	**1-1/2-2 control paring**	**1-2/2-1 Control Paring**
Rise time(Sec) for tank1	**6.06**	6.33
Rise time(Sec) for tank2	4.63	**4.39**
Settling	20.7	20.7

time(sec) for tank1		
Settling time(sec) for tank2	**12**	12.1
Overshoot(%) for tank1	5.27	**5.07**
Overshoot(%) for tank2	**3.46**	4.49

From the tabulation we conclude that 1-1/2-2 control paring is better when compared to 1-2/2-1 control paring.

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