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CH307P Process Control Laboratory

(Jan - May 2024)

Experiment #1

Dynamic Responses of a Quadruple Tank System[1]

Aim of the Experiment

- To study the dynamic response of a quadruple tank system for a step change in voltage to pump 1 for two different operating conditions.
- To study the dynamic response of a quadruple tank system for a step change in voltage to pump 2 for two different operating conditions.

References

[1] K.H. Johansson. The quadruple-tank process: a multivariable laboratory process with an adjustable zero. *IEEE Transactions on Control Systems Technology*, 8(3):456–465, 2000.

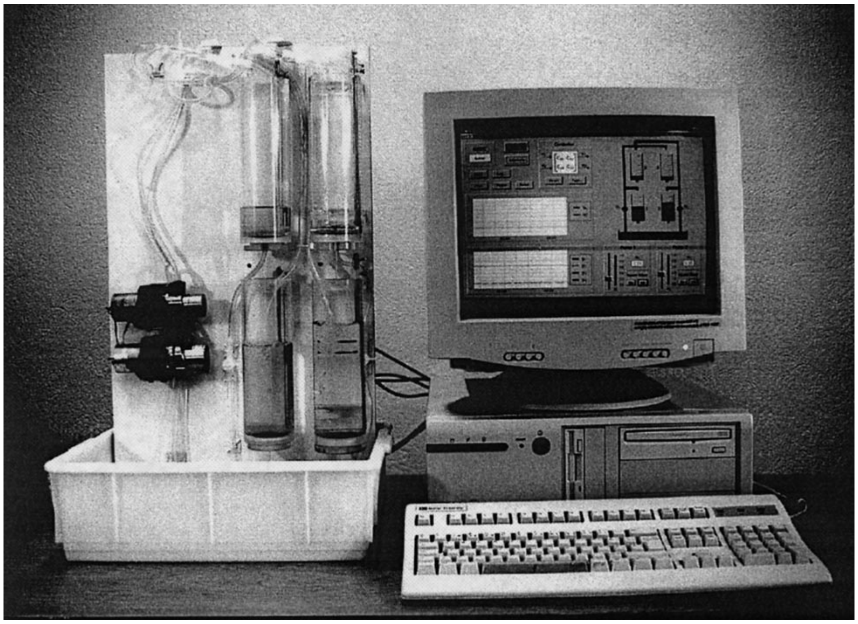

Fig. 1. The quadruple-tank process shown together with a controller interface running on a PC.

A schematic diagram of the process is shown in Fig. 2. The target is to control the level in the lower two tanks with two pumps. The process inputs are v_1 and v_2 (input voltages to the pumps) and the outputs are y_1 and y_2 (voltages from level measurement devices). Mass balances and Bernoulli's law yield

$$\begin{aligned}\frac{dh_1}{dt} &= -\frac{a_1}{A_1}\sqrt{2gh_1} + \frac{a_3}{A_1}\sqrt{2gh_3} + \frac{\gamma_1 k_1}{A_1}v_1\\ \frac{dh_2}{dt} &= -\frac{a_2}{A_2}\sqrt{2gh_2} + \frac{a_4}{A_2}\sqrt{2gh_4} + \frac{\gamma_2 k_2}{A_2}v_2\\ \frac{dh_3}{dt} &= -\frac{a_3}{A_3}\sqrt{2gh_3} + \frac{(1-\gamma_2)k_2}{A_3}v_2\\ \frac{dh_4}{dt} &= -\frac{a_4}{A_4}\sqrt{2gh_4} + \frac{(1-\gamma_1)k_1}{A_4}v_1\end{aligned} \tag{1}$$

where

- A_i cross-section of Tank i;
- a_i cross-section of the outlet hole;
- h_i water level.

The voltage applied to Pump i is v_i and the corresponding flow is $k_i v_i$. The parameters $\gamma_1, \gamma_2 \in (0, 1)$ are determined from how the valves are set prior to an experiment. The flow to Tank 1 is $\gamma_1 k_1 v_1$ and the flow to Tank 4 is $(1-\gamma_1)k_1 v_1$ and similarly for Tank 2 and Tank 3. The acceleration of gravity is denoted g. The measured level signals are $k_c h_1$ and $k_c h_2$. The parameter values of the laboratory process are given in the following table:

A_1, A_3	$[\mathrm{cm}^2]$	28
A_2, A_4	$[\mathrm{cm}^2]$	32
a_1, a_3	$[\mathrm{cm}^2]$	0.071
a_2, a_4	$[\mathrm{cm}^2]$	0.057
k_c	$[\mathrm{V/cm}]$	0.50
g	$[\mathrm{cm/s}^2]$	981.

The model and control of the quadruple-tank process are studied at two operating points: P_- at which the system will be shown to have minimum-phase characteristics and P_+ at which it will be shown to have nonminimum-phase characteristics. The chosen operating points correspond to the following parameter values:

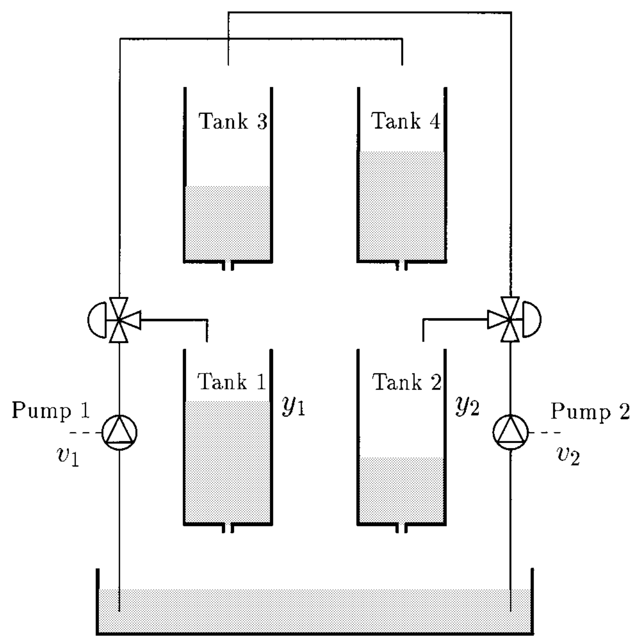

Fig. 2. Schematic diagram of the quadruple-tank process. The water levels in Tanks 1 and 2 are controlled by two pumps. The positions of the valves determine the location of a multivariable zero for the linearized model. The zero can be put in either the left or the right half-plane.

		P_-	P_+
(h_1^0, h_2^0)	$[\mathrm{cm}]$	$(12.4, 12.7)$	$(12.6, 13.0)$
(h_3^0, h_4^0)	$[\mathrm{cm}]$	$(1.8, 1.4)$	$(4.8, 4.9)$
(v_1^0, v_2^0)	$[\mathrm{V}]$	$(3.00, 3.00)$	$(3.15, 3.15)$
(k_1, k_2)	$[\mathrm{cm}^3/\mathrm{Vs}]$	$(3.33, 3.35)$	$(3.14, 3.29)$
(γ_1, γ_2)		$(0.70, 0.60)$	$(0.43, 0.34)$