SIMULATION AND ANALYSIS OF HYDRAULIC-PNEUMATIC QUADRUPLE TANK SYSTEM

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Abstract: This paper presents the simulation and analysis of hydraulic-pneumatic quadruple tank system, which is generally used in industrial processes. The system is complex and has many variables. So, the program tool brings to examine the effects of the system parameters. In addition, this analysis and simulation program provides to teach graduate and undergraduate students without laboratory for hydraulic-pneumatic quadruple tank system. The linear dynamic model is used for the simulation and analysis under some operating conditions. Eventually, some simulation examples are exhibited for the parameter effects.

Keywords: hydraulic-pneumatic, quadruple tank, fluid system, simulation tool.

1. Introduction

The water tank systems are widely used in industrial applications especially for the chemical process systems. The liquid level or flow control between tanks is a prominent issue for many combined tank systems to control some demanded levels of the liquids in the tanks where an outflowing or inflowing of liquid is existent to the tanks. The combined tank systems are multi-input multi-output (MIMO), where inputs are generally pump voltages and the outputs are generally liquid levels. The pumping, storing in tanks of liquids, and then pumping to another tank is orderly needed for the process industry. In critical industries such as petro-chemical and water treatment industries, the tanks have an impact on each other where chemical or mixing processes take up considerable place in process tanks. Therefore, the level control and simulation of liquid systems has a major place in the literature studies. In [1], a new multi-variable laboratory process with four integrated tanks. A sliding mode controller (SMC) based on fractional order (FO) is designed for a level control of coupled tank in [2] whereas SMC is designed for quadruple tank process in [3] and coupled-tank system in [4]. In [5], the control of the liquid levels and temperature for combined three tanks is made via feedback linearization, a decentralized fuzzy logic control is performed by LabVIEW for a coupled-tank process in [6] and [7]. In [8], a FO-PI controller is designed for a liquid level of round tank. In [9], a linear quadratic regulator (LQR) and a type-2 fuzzy logic are designed on the level control of three-tank system. In [10], FO-PI controller is performed for a coupled two-tank system. In [11], fuzzy logic control is fulfilled for a tank system. In [12], an adaptive model reference controller is designed for a hybrid nonlinear tank system. In [13], controller based quadratic programming is proposed for a quadruple tank problem. In [14], a corrected mathematical model is proposed for quadruple tank system.

LabVIEW™ is a sufficient simulation and analysis program for the academic computation, process systems, measurement and industrial implementations due to the fact that it has a flexible program which is together with many tools particularly for the measurements, controls, and tests as in [15]. It is also an sufficient program for learning and teaching because it satisfies several requirements for a lot of applications [16]. Some of laboratory sets are quite expensive. In addition, many of them cannot give the changing their parameters such as chemical process, power systems, robotic systems. So, a virtual
A laboratory or analysis tool is sufficient to analyze the changings of parameter. Some systems which are not experimental can be difficult to good understand in view of the teaching and learning of students. In addition, to be perceived the influences of the system parameters on the operating are limited by many students. In the literature, the researchers have been investigated on the educational virtual tools for a lot of systems such as [17]–[19]. In this paper, an educational analysis tool is designed with LabVIEW for the hydraulic-pneumatic quadruple tank. They have been used in undergraduate chemical and mechatronics engineering laboratories in a lot of universities.

2. The Hydraulic-Pneumatic Quadruple Tank System Model

A new process is proposed for the four tanks in [20]. Figure 1 shows this process. In this process, pneumatic volume above the water levels is connected. Also, the orifices are replaced into the circuits, so, the cross interactions exist only in transient states so the working area is not reduced [20]. It has an integration of pneumatic and hydraulic parts. The circuits of pneumatic bring about cross coupling between both classical couple tank parts. Four cylindrical tanks are the basic elements. The water is pumped into left upper (LH) and right upper (RH) tanks by two pumps and so, it flows into left lower (LL) and right lower (RL) tanks. Then, it backs into the reservoir. Water flow rates are controlled by $u_L$, $u_R$ voltages of the pumps between 0 and 10 volts, which is amplified into 4-10 volts. Difference pressure sensors indirectly measure the lower tanks. The pressure sensor outputs are between 0 and 10 volts. Air spaces above the tank levels are connected by pneumatic circuits H and L with the changeable valves. The orifices in air gaps work as a coupling between atmosphere and pneumatic volumes. The structure can be changed by the size of orifices and by valves in the pneumatic circuits. There is a atmospheric pressure in pneumatic in the steady-state. The water level changes by the pressure in pneumatic. The air is progressively equilibrated with atmospheric pressure by flowing in the air chambers. Thus, the multi-variable adverse effect has only dynamic property.

![Hydraulic-Pneumatic Quadruple Tank System](image_url)
\[
\frac{d \Delta h_{LH}}{dt} = -\frac{1}{T_L} \Delta h_{LH} + \frac{Z}{T_L} \Delta h_{LL} + \frac{Z_{ul}Z_{QL}}{T_L} \Delta u_L \\
\frac{d \Delta h_{RH}}{dt} = -\frac{1}{T_R} \Delta h_{RH} + \frac{Z}{T_R} \Delta h_{RL} + \frac{Z_{QR}Z_{ur}}{T_R} \Delta u_R \\
\frac{d \Delta p_L}{dt} = -\frac{Z_{hl}}{T_p} \Delta h_{LH} + \frac{Z_{hl}}{T_p} \Delta h_{RH} - \frac{1}{T_p} \Delta p_L - \frac{Z_{hl}}{T_p} \Delta h_{LL} - \frac{Z_{hr}}{T_p} \Delta h_{RL} \\
\frac{d \Delta h_{LL}}{dt} = \frac{1}{T_L} \Delta h_{LH} - \frac{2Z}{T_L} \Delta p_L - \frac{1}{T_L} \Delta h_{LL} \\
\frac{d \Delta h_{RL}}{dt} = \frac{1}{T_R} \Delta h_{RH} - \frac{2Z}{T_R} \Delta p_L - \frac{1}{T_R} \Delta h_{RL} 
\]

(1)

According to the equations, the linear state space model is in (2) where all expressions are detailed in [20].

\[
\dot{x} = A(x) + B(x)u \\
A = \begin{bmatrix} -\frac{1}{T_L} & 0 & \frac{Z}{T_L} & 0 & 0 \\
0 & -\frac{1}{T_R} & \frac{Z}{T_R} & 0 & 0 \\
-\frac{Z_{hl}}{T_p} & -\frac{Z_{hl}}{T_p} & -\frac{1}{T_p} & -\frac{Z_{hl}}{T_p} & -\frac{Z_{hr}}{T_p} \\
\frac{1}{T_L} & 0 & -\frac{2Z}{T_L} & -\frac{1}{T_L} & 0 \\
0 & 1 & -\frac{2Z}{T_R} & 0 & -\frac{1}{T_R} \end{bmatrix}, \quad B = \begin{bmatrix} \frac{Z_{ul}Z_{QL}}{T_L} & 0 \\
0 & \frac{Z_{QR}Z_{ur}}{T_R} \\
0 & 0 \\
0 & 0 \\
0 & 0 \end{bmatrix}, \quad \begin{bmatrix} \Delta h_{LH} \\
\Delta h_{RH} \\
\Delta p_L \\
\Delta h_{LL} \\
\Delta h_{RL} \end{bmatrix} = (A, B, u) 
\]

(2)

3. The Simulation and Analysis for the Quadruple Tank System

An analysis tool is designed via LabVIEW™. The tool gives the teachers to prove the system behaviour and all effects of parameters in the system model without any laboratory. Such a laboratory may be costly or the parameter effects are not proved since system parameters are fix. Therefore, all parameter effects on the system are examined owing to the tool. Figure 2 presents LabVIEW control front panel for the designed tool. As in Figure 2, all parameters can be changed with buttons and the tank levels are observed as visually. Thus, by modifying all system parameters with the tool interface, their effects can be observed on the system. Also, a designer can examine the crucial parameters by the tool for the validation or control. The default parameter values of the system are as in [20] for the simulation.

The tool is simulated to examine the parameter effects on the system. For instance, to observe the pump voltage inputs, the changings of liquid levels are in Figure 3. So, the effects of the inputs are examined when \( \Delta_{ul} \) and \( \Delta_{ur} \) are 5V at the simulation. For another example, Figure (4a) shows the liquid levels when left pump specific coefficient is changed from 0.00798 to 0.01368 whereas Figure (4b) shows the liquid levels when left pump specific coefficient is changed from 0.00853 to 0.01053. Thus, the effects of pump coefficients are on left and right upper tanks. Similarly, by changing the other parameters, the effects can be observed.
Fig. 2. The designed Labview front panel.

Fig. 3. The liquid levels according to the changes of voltage inputs.

Fig. 4. The liquid levels according to the changes of pump coefficients.
According to the simulation results, the whole parameter effects can be analysed by help of the tool. Finally, the designed simulation tool is very beneficial for the learning and teaching. Moreover, the tool is developed by the controller and thus the controller effects can be examined.

5. Conclusions

In this paper, an educational simulation tool is performed for hydraulic-pneumatic quadruple tank model. This tool gives users to modify of system variables, and so they can observe the outputs as visually. It helps students to improve modelling and dynamic system behaviour without any laboratory for the system. In particular, the simulation tool allows either undergraduate or graduate students to compass the parameter influences on the system model. Finally, simulation results show that the students can easily catch the parameter differences and their influences with the analysis tool.

References
