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Implementation of an adaptive fuzzy compensator for coupled tank liquid level control system

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ABSTRACT

In this paper, an adaptive fuzzy control (AFC) system is proposed to realize level position control of two coupled water tanks, often encountered in practical process control. The fuzzy control system includes an adaptive model identifier and controller. The gains of AFC are obtained by using the fuzzy identifier model which is defined by real system outputs and control inputs. The parameters of fuzzy identifier model are adjusted online by using recursive least square algorithm. Because the controller has a recursive form it treats model uncertainties and external disturbances in an implicit way. Thus there is no need to specify uncertainty and disturbances for this controller design in advance. A well-tuned conventional proportional integral (PI) controller is also applied to the two coupled tank system for comparison with the AFC system. Experimentation of the coupled tank system is realized in two different configurations, namely configuration #1 and configuration #2 respectively. In configuration #1, the water level in the top tank is controlled by a pump. In configuration #2, the water level in the bottom tank is controlled by the water flow coming out of the top tank. Experimental results prove that the AFC shows better trajectory tracking performance than PI controller in that the plant transient responses to the desired output changes have shorter settling time and smaller magnitude overshot/undershoot. Robustness of the AFC with respect to water level variation and capability to eliminate external disturbances are also achieved. Experimental results show that AFC is a strong and a practical choice for liquid level control.

1. Introduction

Liquid level control is a typical representation of process control and is widely used in the area of water purification, chemical and biochemical processing, automatic liquid dispensing, food and beverage processing, and pharmaceutical industries. The control quality directly affects the quality of products and safety of equipment. However, the coupled tank liquid level control system is a large lag, nonlinear and complex characteristics, in which the control accuracy is directly affected by system status, system parameters, and the control algorithm. Therefore, it is quite difficult to perform a high precision servo control by using linear control methods. To perform high precision liquid level control and good tracking precision in the presence of the system nonlinearities and parameter uncertainties, it is needed to use nonlinear control method to solve these problems effectively and achieve precise control. As a solution, sliding mode techniques have been introduced to compensate the uncertainties in dynamics and/or kinematics [1–6]. The sliding mode control is robust with respect to uncertainties in the system and external disturbances. However, this control methodology has some disadvantages associated with a large control chattering. Also neural network [7–11] and genetic algorithm [1,2,12,13] based controllers are proposed as an effective tool for nonlinear controller design. Both controllers offer exciting advantages such as adaptive learning, fault tolerance, generalization and disadvantages such as complex learning algorithm and computational requirement. Many existing experiments have demonstrated that an adaptive fuzzy controller can be applied to the system whose dynamic model is not well defined or not available at all and has proven to be a strong tool for controlling nonlinear systems [14–18]. In addition to handling nonlinear problems, adaptive fuzzy control can also enhance the robustness of the system.

In this paper, the proposed AFC and conventional PI controllers are used for level control of experimental setup of liquid level system, respectively. The coupled tank system is used in two different configurations, namely configuration #1 and configuration #2. Our study is focused on the level control of top tank in configuration 1 and level control of bottom tank in configuration 2. The experimental results obtained prove that the AFC is robust to liquid level

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changes as well as to disturbances as compared to PI controller and can also follow command trajectories very well.

2. Modeling and control of the coupled tank system

2.1. Single tank model (Configuration #1)

Single tank system which consisting of the top tank is shown in Fig. 1. It is reminded that in configuration #1, the pump feeds into tank 1 and that tank 2 is not considered at all.

Therefore, the input to the process is the voltage to the pump and its output is the water level in tank 1. The mathematics model of the single tank system determined by relating the volumetric inflow rate f_{i1} into tank to the outflow rate f_{o1} leaving through the hole at the tank bottom. The volumetric inflow rate and the outflow rate to tank 1 can be expressed as [19],

$$f_{i1} = K_p V_p \tag{1}$$

$$f_{o1} = A_{o1} v_{o1} \tag{2}$$

where A_{o1} is the outlet cross sectional area, v_{o1} is the tank 1 outflow velocity, K_p is the pump volumetric flow constant and V_p is the actual pump input voltage. The outflow velocity by using Bernoulli's equation

$$v_{o1} = \sqrt{2}\sqrt{gL_1} \tag{3}$$

where g is the gravitational constant on earth. As a remark, the cross-section area of tank 1 outlet hole can be calculated by,

$$A_{o1} = \frac{1}{4}\pi D_{o1}^2 \tag{4}$$

in the Eq. (4) D_{o1} is the tank 1 outlet diameter. Using Eq. (3) the outflow rate from tank 1 given in Eq. (3) becomes,

$$F_{o1} = A_{o1}\sqrt{2}\sqrt{gL_1} \tag{5}$$

Moreover using the mass balance principle for tank 1, we obtain the following first-order differential equation in L_1

$$A_{t1}\left(\frac{\partial}{\partial t}L_1\right) = f_{i1} - f_{o1} \tag{6}$$

where A_{t1} is tank 1 inside cross-section area. Substituting Eqs. (1) and (2) into Eq. (6) and it can be rearranged in the following form for the tank 1 system,

$$\frac{\partial}{\partial t}L_1 = \frac{K_p V_p - A_{o1}\sqrt{2}\sqrt{gL_1}}{A_{t1}} \tag{7}$$

2.2. Coupled tank model (Configuration # 2)

A schematic of the coupled tank plant is depicted in Fig. 2.

In configuration #2 the pump feeds into tank 1, which in turn feeds into tank 2. As far as tank 1 is concerned, the same equation as the ones previously developed in Section 2.1 is applied. However, the water level equation of motion in tank 2 still needs to be derived. In the coupled tank, the system states are the level L_1 in tank 1 and the level L_2 in tank 2. The outflow rate from tank 2 can be expressed as;

$$f_{o2} = A_{o2} v_{o2} \tag{8}$$

Tank 2 outflow velocity by using Bernoulli's equation

$$v_{o2} = \sqrt{2}\sqrt{gL_2} \tag{9}$$

As a remark, the cross-section area of tank 2 outlet hole can be calculated by,

$$A_{o2} = \frac{1}{4}\pi D_{o2}^2 \tag{10}$$

Using Eqs. (9) and (10) the outflow rate from tank 2 given in Eq. (8) becomes

$$F_{o2} = A_{o2}\sqrt{2}\sqrt{gL_2} \tag{11}$$

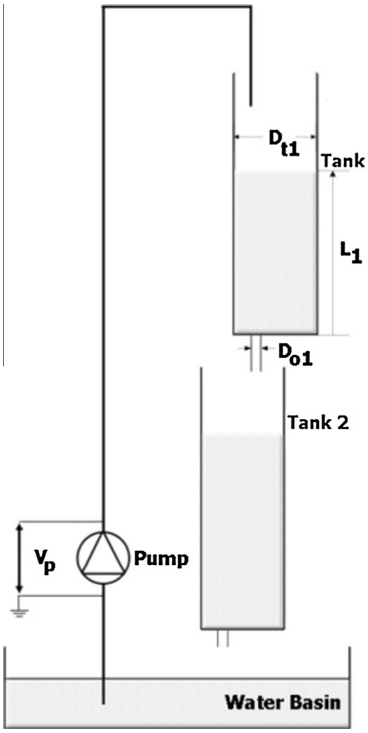

Fig. 1. Tank configuration #1.

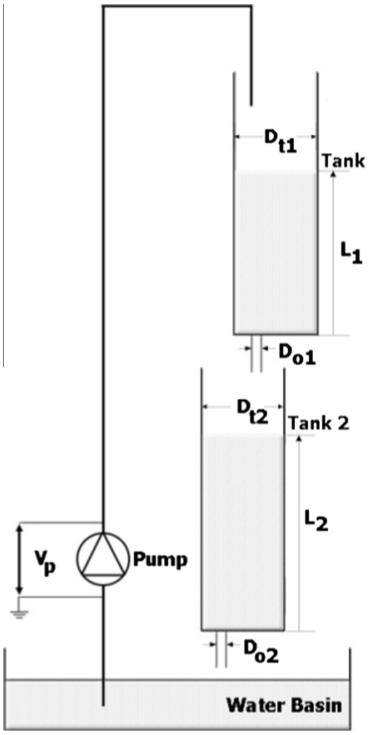

Fig. 2. Tank configuration #2.