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Research Article

Dual mode adaptive fractional order PI controller with feedforward controller based on variable parameter model for quadruple tank process

Prasanta Roy *, Binoy Krishna Roy

Department of Electrical Engineering, NIT Silchar, Assam, India

A R T I C L E I N F O

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A B S T R A C T

The Quadruple Tank Process (QTP) is a well-known benchmark of a nonlinear coupled complex MIMO process having both minimum and nonminimum phase characteristics. This paper presents a novel self tuning type Dual Mode Adaptive Fractional Order PI controller along with an Adaptive Feedforward controller for the QTP. The controllers are designed based on a novel Variable Parameter Transfer Function model. The effectiveness of the proposed model and controllers is tested through numerical simulation and experimentation. Results reveal that the proposed controllers work successfully to track the reference signals in all ranges of output. A brief comparison with some of the earlier reported similar works is presented to show that the proposed control scheme has some advantages and better performances than several other similar works.

1. Introduction

The Quadruple Tank Process (QTP) was first introduced by Johansson in 2000 [1]. Since its inception the QTP is a well-known benchmark to test advanced control strategies for multivariable control because of having both minimum and nonminimum phase characteristics depending upon its configuration and operating points. It has an adjustable transmission zero whose location varies from left half to right half of *s*-plane based on the split fraction of water between the upper and lower tanks. This physically means that in the minimum and nonminimum phase zones the lower and upper tanks get more water, respectively, and vice versa. A QTP experimental setup manufactured by Feedback Instruments Ltd., UK. (Model no. 33-041S) is considered here. A schematic diagram of the experimental setup is shown in Fig. 1.

1.1. Contribution and novelties

In this paper a level control problem in the Quadruple Tank Process (QTP) is considered. The novel contributions of this paper are as below:

(i) The QTP considered here is more challenging to control than those available in the existing literature. It is shown experimentally that the characteristic of the QTP toggles between minimum phase and nonminimum phase during running condition and thus, the control problem becomes more challenging. The existing controllers in the literature are designed with the assumption that the QTP remains either in minimum or in nonminimum phase. The existing literature also shows that a particular control strategy works well either in minimum phase or in nonminimum phase zone. But no such controller which can control the QTP in both the minimum and nonminimum phase zone are present in the existing literature to the best of knowledge of the authors. In this paper a novel modelling and a novel control strategy are proposed which can control the QTP in both the minimum and nonminimum phase zone with equally good performance.

(ii) A Variable Parameter Transfer Function (VPTF) model of the QTP is proposed. It is experimentally validated that the proposed VPTF model represents the QTP better than its nonlinear phenomenological model in all ranges of input and output. VPTF can take care of the variation in plant parameters during running condition. Moreover, having a transfer function like structure, it is designer friendly for classical controller.

(iii) A novel self tuning type Dual Mode Adaptive Fractional Order PI (DMAFOPI) controller along with an Adaptive Feedforward (AF) controller is proposed. Switching control between

* Correspondence to: Department of Electrical Engineering, National Institute of Technology Silchar, Assam 788010, India. Tel.: +91 7896216129.
E-mail address: proy.iitkgp@gmail.com (P. Roy).

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0019-0578/

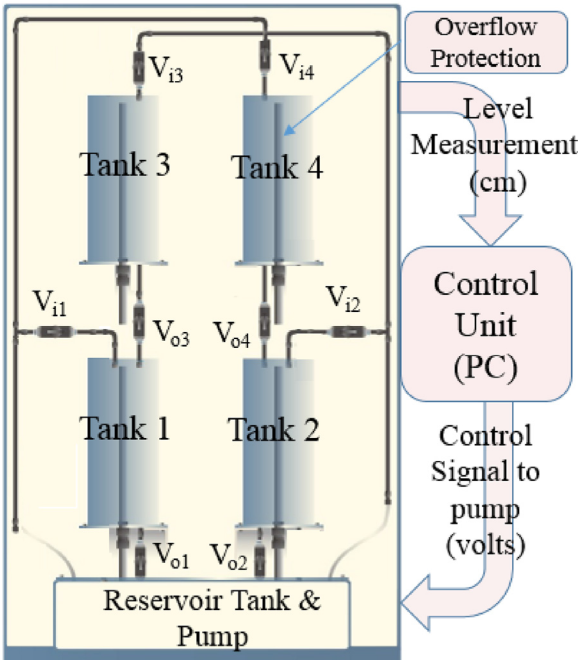

Fig. 1. Schematic diagram of the QTP experimental setup.

different modes, self tuning adaptive controller, fractional order PI controller, and feedforward controller are well established control strategies. These control schemes are not only hybridised but some novelties are also introduced into the hybridised structure as given below:

(a) The dual mode is used to toggle the structure between two suitable modes to take care of both the minimum and non-minimum phases.
(b) The Adaptive Feedforward (AF) controller does the decoupling and proactive disturbance rejection.
(c) The Adaptive Fractional Order PI (AFOPI) controller ensures the set point tracking and residual disturbance rejection due to imperfect feedforward control.
(d) Instead of following the usual adaptation method of self tuning type adaptive controllers, here the adaptation of controller parameters is done based on the proposed VPTF model. This reduces the online computational burden.
(e) The online adaptation of the order of integration in AFOPI is challenging. This is successfully done here. This is not done previously as per the best of the knowledge of the authors.
(f) Although the plant is an interactive MIMO system, the control strategy is a simple SISO like control strategy based on the classical frequency domain approach which is simple to design.

(iv) A comparative analysis with other reported work is presented. This shows that the proposed methods have several advantages and better performances over some of the earlier reported works on QTP.

1.2. A brief literature review

Literature survey is carried out considering the state of the art control schemes for level control in QTP available in recent literature. The existence of adjustable transmission zeros in QTP along with its physical interpretation is illustrated by Johansson in [1]. A decentralized PI controller is designed to control the QTP, based on a model derived using system identification technique in [1]. A static decoupling technique along with a modified PI controller is used in [2] which basically does a trade off between individual loop performances and the interaction between the loops. A quantitative feedback theory based controller, considering tracking error specification is presented in [3]. The nonlinearity in the split fractions and in the conductance at tank outlets is considered by [4] and a Sliding Mode Controller (SMC) is designed. Multivariable dead zones are introduced in QTP and a decentralised integral control scheme is proposed in [5]. Transport delays are introduced in a standard QTP in [6] and a delay dependant stabilisation is applied to take care of that. A distributed Model Predictive Controller (MPC) is proposed in [7] based on the discrete time state space model of a QTP. A decoupling based distributed multiparametric MPC is proposed in [8] based on the constraint satisfaction, stability and optimality. A decentralised PI controller is proposed in [9] based on the phase margin specification using direct Nyquist array. A fractional order SMC is designed considering a fractional order sliding surface in [10] on a modified QTP where an extra coupling between the bottom tanks is introduced.

1.3. Motivations and prime objectives

While carrying out the literature survey authors observe that much emphasis is not given for accurate modelling of the QTP in the existing literature. Most of the literatures followed a modelling approach based on Bernoulli's law and mass balance. There exists unmodelled nonlinear dynamics due to various reasons in the QTP setup under consideration as given below:

(i) The relation between pump voltage and input flow rate is nonlinear due to the nonlinear dynamics of the pump.
(ii) The nonlinearity in valves causes different split fractions of flow at different flow rates.
(iii) The flow channels are mounted at different heights along with bending, hence pressure drops at different flow rates introduces nonlinearity.
(iv) The outlet of each tank is connected to the tank body through a joint having nonuniform cross section which generates different differential pressures for different water level. At a very low level of water eddy effect also comes into play.
(v) The inlet to the tanks are mounted over the tanks. So when the input flow falls at higher rate, it causes slothing and turbulence in the water.

Moreover, it is experimentally found (discussed in Section 2) that the QTP under consideration does toggle between the minimum and nonminimum phase characteristics with change in input and makes the control problem more difficult and challenging. These all motivated the authors to carry out the present work with the following objectives:

(i) To highlight the characteristics of QTP, its significance, challenges in level control of QTP, limitations of earlier reported works in level control of QTP.
(ii) To propose and obtain a novel VPTF model which is not only designer friendly, but also represents the QTP better than its phenomenological model.
(iii) To cross-validate experimentally that the proposed VPTF model represents the QTP better than its phenomenological nonlinear model.
(iv) To design a novel self tuning type DMAFOPI controller along with an AF controller.
(v) To test the effectiveness of the proposed controllers on the experimental setup.
(vi) To provide a brief comparative analysis of the proposed controllers with the earlier reported similar works.

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