DIRECT MODEL REFERENCE ADAPTIVE CONTROL OF COUPLED TANK LIQUID LEVEL CONTROL SYSTEM

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To my loving parents Abah and Mama,
my brothers and sisters
thanks
for all their support, motivation and caring
during the course of this project.

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ABSTRACT

Industries such as petro-chemical industries, paper making industries, waste management and others are the vital industries where liquid level and flow control are essential. Liquids will be processed by chemical or mixing treatment in the tanks, but always the level fluid in the tanks must be controlled, and the flow between tanks must be regulated in the presence of nonlinearity and inexact model description of the plant. This project investigates the usage of Direct Model Reference Adaptive Control (DMRAC) in controlling the liquid level in the second tank of Coupled-Tank plant through variable manipulation of water pump in the first tank. It is to show that DMRAC could produce appropriate control signal to the coupled-tank system in response to the given desired water level with plant nonlinearity and measurement noise present simultaneously. The ability to use only input-output measurement of the plant in adaptation mechanism is the DMRAC's special characteristics that does not require the explicit identification of the model description nor the solution to linear(or nonlinear) equations of the respective plant dynamics. A dynamic model of the plant is initially developed. Simulation studies are then conducted based on the developed model using Matlab and Simulink. A series of tracking performance tests, disturbance rejection and plant parameter changes are conducted to evaluate the controller performance in comparison to PID controller. The outcome of the project reveals that DMRAC is more robust than PID controller when there is a change in system parameters despite of its sensitivity to measurement noise. The framework of this project is generic enough to have an overview of the possible outcome before implementing the DMRAC controller in real-time system in the future.

ABSTRAK

Industri petrokimia, industri pembuatan kertas, dan lain-lain merupakan industri utama dimana kawalan aras cecair dan arus adalah penting. Lazimnya, cecair-cecair itu akan diproses secara rawatan kimia atau pencampuran dalam tangki tetapi selalunya aras cecair dalam tangki tersebut perlu dikawal dan arus antara tangki perlu diteraturkan dalam keadaan sistem yang sememangnya tidak linear dan modelnya kurang maklumat. Projek ini menyelidik penggunaan *Direct Model Reference Adaptive Control* atau DMRAC dalam pengawalan aras cecair pada Tangki kedua dalam system tangki berkembar dengan memanipulasikan pam air di tangki pertama. Ini bagi menunjukkan bahawa DMRAC dapat menghasilkan isyarat kawalan yang munasabah dalam kawalan aras cecair bagi system, hasil daripada tindakbalas kepada titik rujukan aras cecair yang diberi dalam keadaan sistem yang tidak linear dan terdapatnya pengukuran hingar dalam proses secara serentak. Kebolehan menggunakan hanya pengukuran masukan-keluaran dalam mekanisma adaptasi ialah merupakan cirri-ciri istimewa bagi DMRAC dimana ia tidak perlukan pengenalanpastian eksplisit bagi sistem model. Ia juga tidak memerlukan penyelesaian terhadap dinamik persamaan linear (atau tidak linear) bagi system tersebut. Ujian prestasi penjejakian (tracking performance test), penyisihan gangguan dan perubahan parameter sistem telah dijalankan untuk menilai prestasi pengawal DMRAC dan dibandingkan dengan prestasi pengawal PID. Hasil daripada projek ini menunjukkan DMRAC lebih *robust* berbanding dengan PID dimana system perubahan parameter tidak memberi kesan pada DMRAC walaupun ia sedikit sensitif terhadap hingar. Rangka projek ini adalah umum dalam memberi gambaran keseluruhan pada kemungkinan yang akan berlaku apabila pengawal DMRAC dilaksanakan untuk sistem masa-nyata.

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LIST OF SYMBOLS

A_i - Cross Sectional Area of the respective *i* coupled tank reservoir

α_i - Proportionality constant that depends on discharge coefficient, orifice cross sectional area and gravitational constant

K_{sensor} - Sensor gain

K_{pump} - Pump gain

$Qimax$ - Maximum allowable volumetric flowrate pumped by motor

TC - Pump motor(valve) time constant

H_1, H_2 - height of liquid in tank 1 and tank 2 respectively

Q_{o3} - flow rate of liquid between tanks

Q_{i1}, Q_{i2} - pump flow rate into tank 1 and tank 2 respectively

Q_{o1}, Q_{o2} - flow rate of liquid out of tank 1 and tank 2

$Q_c(t)$ - computed or the commanded flow rate

$q_i(t)$ - the time-varying input flow rate

τ_a - Time constant of actuator

V - Lyapunov function

$\dot{V}$ - Time derivative of Lyapunov function

$K_e(t)$ - Stabilizing gain (time varying)

$K_x(t)$ - Adaptation gain from reference model state vector (time varying)

$K_u(t)$ - Adaptation gain from commanded setpoint (time varying)

$u_p(t)$ - Control law (time varying)

T - Adaptation weights for Integral adaptation

$\overline{T}$ - Adaptation weights for Proportional adaptation (time varying)

$K_I(t)$ - Proportional adaptation (time varying)

$K_p(t)$ - Integral adaptation

σ - Forgetting Factor

e_x - State error

CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, the process industries such as petro-chemical industries, paper making and water treatment industries require liquids to be pumped, stored in tanks, and then pumped to another tank. The control of liquid in tanks and flow between tanks is a basic problem in the process industries. The above mentioned industries are the vital industries where liquid level and flow control are essential. Many times the liquids will be processed by chemical or mixing treatment in the tanks, but always the level fluid in the tanks must be controlled, and the flow between tanks must be regulated. Level and flow control in tanks are the heart of all chemical engineering systems.

Due to the nonlinearity of the coupled tank system, MRAC or model reference adaptive control which is one of a kind in adaptive control techniques is implemented. It is regarded as an adaptive servo system in which the desired performance is expressed in terms of reference model, which gives the desired response to a command signal. The nonlinearity occurs because the system transfer function varies or changes with the height of the liquid in a tank and the controller ought to be adaptive and robust for these changes.

1.2 Problem statements

The first and foremost important step before formulating a controller, a mathematical relationship or the governing dynamics between the input and the output of the system should be known. The underlying principle and knowledge of the system should be investigated to comprehend the occurrence of nonlinearity in the system dynamics. There are wide arrays of control techniques that can be applied to meet the control objective of the system and these depend on the factors of which the proposed design objective might rely on. There are factors such as tracking, reducing the effects of adverse conditions and uncertainty, behaviors in terms of time response (e.g., stability, a certain rise-time, overshoot, and steady state tracking error) and lastly engineering goals such as cost and reliability which is vital in industrial perspective.

Sophistication of controller scheme primarily depends on the degree of how the nonlinearity can be tolerated and assumed using the linearization theory. Moreover, apart from nonlinearities, there may be a consequence of unknown parameters which hinders the objective to obtain a complete detail model of a process available for control purpose. The factors that abstained many researchers to use conventional control theory and techniques can be listed as follows:-

i. Systems are nonlinear and may contain unknown parameters. That unknown parameters may not be estimated accurately if reliable experimental data is absent.
ii. The delays present in the process of system (coupled tank system specifically) might complicate achieving high performance control.
iii. There are several cases such as that of couple tank in industry where the process or disturbance characteristics are changing continuously. This requires simultaneous regulation of various variables in order to maintain the desired liquid level. Thus, a model must account for all of the most significant variables of the process.

Due to the above mentioned factors, it might be difficult to formulate a control strategy based on the analytical model because the mathematical model is usually linearised to account for complexity and nonlinearity which are inevitable in a complicated system. PID(proportional-integral-derivative) control is one of a kind of control scheme that uses the approach of linearised model. However, the PID controller might not capable to satisfy the control objectives or requirement at all times as it need to be regularly tuned due to the varying system dynamics.

Hence, it is desirable to have a robust and reliable control technique for modeling the complex and nonlinear system that prevails in all industrial process. MRAC or model reference adaptive control is chosen as the coupled tank's control scheme. It is regarded as a novel approach in parameter adjustment for a system where process dynamics are nonlinear.

1.3 Objectives

The objectives of the project can be outlined likewise:

i. To develop an adaptive system for a couple tank system using DMRAC (Direct Model Reference Adaptive Control).

ii. To investigate the performance of DMRAC (Lyapunov and Positivity concept) in control of coupled-tank and compare with the system controlled by PID controller.

1.4 Scope of the project

The purpose of this project can be divided into four parts, the first part is to develop and validate a mathematical dynamic model that represents the coupled-tank control apparatus. This includes models for first order and second order system as well as the nonlinear model of the system.

Then, after the models are approved of its validity, simulation will be performed using engineering simulation software like Matlab Simulink to simulate its dynamic characteristic using the actual plant parameters obtained from laboratory. A step test was performed on the nonlinear model of the coupled-tank system by simulation to observe various important dynamic characteristics at different operating conditions(water level). This is to investigate the behaviour of the system at certain range of operating conditions and thus, will give a guideline in the development of a reference model for the system to track.

The third part of the project will follow consequently after the second part and this involves the design of the controller; firstly normal PID control, then followed by the adaptive controller (DMRAC). Normal PID control, with expectation in mind, will exhibits its limitation in coping with nonlinearities and changes in process gain. DMRAC will be developed by implementing a suitable adaptive algorithm that will make the nonlinear system be able to adapt to set point changes(servo) and sudden load disturbances (regulator). The final part will comprise of brief comparative study based on performance of the two controllers.

1.5 Summary

This section explains the objective as well as the scope of the project in order to give an insight and the sense of direction of this project. The next subsequent chapter will be literature review section, discussing on the research works previously done by other researchers concerning on the liquid level control of coupled tank system. Different control strategies are demonstrated by various researchers in the literatures and are evaluated in comparison with other controllers.

The augmentation of feedforward compensator in all three configurations can guarantee stability of more realistic systems. Special attention must be given on the method of designing these extended DMRAC algorithms.

Finally, it is of great interest to implement the DMRAC algorithm on the real time system for future works purpose. The real time implementation requires the DMRAC algorithm to be in digitized form. Therefore, special care should be taken in the digital domain and some of them can be summarized as follows,

i. The gains may be computed at the same frequency as the control update frequency or slower. Euler type algorithm should be adequate for computing the integral gain K_I.

ii. The reference model output and state vectors can be computed digitally at any assigned sampling frequency.

iii. It is desirable for the outputs to be sensed sufficiently fast with adequate computing power in order for all the functions to be computed at the same frequency.

iv. If the reference model time constants are relatively small and demand control frequency faster than the sensor frequency, then the sensed outputs may have to be interpolated to give values at intermediate times.

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