PID CONTROL TUNING USING CUCKOO SEARCH FOR MULTI-INPUT MULTI-OUTPUT COUPLED TANK SYSTEM

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APPROVAL

“I hereby declare that I have read this project entitle “PID Control Tuning Using Cuckoo Search for Multi-input Multi-output Coupled Tank System” and that is has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)”

Signature	: ………………………………...
Supervisor’s Name	: Puan Nur Asmiza Binti Selamat
Date	: 1 June 2015

DECLARATION

I declare that this report entitle "PID Control Tuning Using Cuckoo Search for Multi-input Multi-output Coupled Tank System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	: ……………………………..
Name	: Muhammad Faiz Bin Pungot
Date	: 1 June 2015

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ABSTRACT

Coupled tank system can be found easily and widely used in industrial process. Multi-input Multi-output (MIMO) coupled tank system is a big tank separate into two tank by baffle that place in the middle of the tank. It involves two input with two output. Proportional Integral Derivative (PID) controller is used to tuning the parameter of the tank. Trial and error method still been used and it takes a long time. The system performance using trial and error method is not efficient. The objective of this project is to analyze the system performance between Cuckoo Search and Particle Swarm Optimization. Hence, two techniques of optimization which is Cuckoo Search (CS) and Particle Swarm Optimization (PSO) are used the tuning the PID controller. The tuning parameters that obtained after optimization will be applied to MIMO coupled tank system. The comparison between both optimizations will be made and observed. As for the result, it will show that tuning using (CS) will give better performance compared tuning using (PSO).

ABSTRAK

Sistem tangki berkembar boleh didapati dengan mudah dan banyak digunakan di proses industri. Sistem tangki berkembar dua masukan dan dua keluaran sistem adalah satu tangki yang besar dipisahkan pada dua tangki dengan meletakkan pemisah di tengah-tengah tangki tersebut. Ia melibatkan dua masukan dengan dua keluaran Pengawal PID digunakan mengawal parameter tangki tersebut. Kaedah "trial and error" masih lagi digunakan dan mengambil masa yang lama. Prestasi sistem menggunakan kaedah tersebut adalah kurang cekap dan kurang tepat. Objektif projek ini adalah untuk membandingkan perbezaan prestasi sistem antara Cuckoo Search dan Particle Swarm Optimization. Justeru itu, dua teknik pengoptimuman iaitu Cuckoo Search (CS) dan Particle Swarm Optimization (PSO) telah digunakan untuk mengawal pengawal PID. Hasil dari pengawalan selepas proses pengoptimuman telah diaplikasikan terhadap sistem tangki berkembar dua masukan dua keluaran. Perbezaan diantara kedua (CS) dan (PSO) akan dibandingkan. Sebagai hasilnya, ia akan menunjukkan bahawa pengoptimuman menggunakan (CS) akan menunjukkan hasil yang lagi baik berbanding (PSO).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Motivation

Coupled tank system can be found easily and widely used in industry such as food processing and industrial chemical processing. Multi-input multi-output coupled tank system (MIMO CTS) is a two tank connected each other by a valve between both tanks. It causes the water level in both tanks to interact. The water level for both tank need to be controlled. The PID controller will be apply to the MIMO CTS. The PID control tuning used in the MIMO CTS system need to be tuned in more effective and better tuning to improves the performance of the MIMO CTS. Two different optimization technique will be used in this study to obtain the parameter tuning.

1.2 Problem Statement

Single-input Single -Output system (SISO) coupled tank system is mostly used compare to Multi-input Multi-Output (MIMO) coupled tank system. Therefore, MIMO system is used. PID controller is used to get the desirable output value and to increase the system performance. PID controller can be used for both SISO and MIMO system. To determine the parameter tuning in PID, trial and error method still been used. This method takes a long time and not guaranteed to give the best performance and efficient result. Hence, tuning parameters based on the optimization techniques were proposed in the study.

1.3 Objectives

The aim of this project is to obtain the parameter for the PID tuning for MIMO CTS using optimization technique. Therefore, the objectives are:

1. To implement the PID control tuning to MIMO coupled tank system
2. To analyze system performance in terms of rise time, peak time, overshoot percentage, settling time and fitness function between particle swarm optimization (PSO) and Cuckoo Search (CS).

1.4 Scope of Research

This study focuses on the PID control tuning in MIMO coupled tank system. The MIMO transfer function will be obtained from previous research [16]. The PID parameter will be tuned using optimization techniques which are Particle Swarm Optimization (PSO) and Cuckoo Search (CS). All simulation work will be done using MATLAB software.

1.5 Report Outlines

This report is divided into five chapters;

Chapter 1 – Introduction

This chapter describes about the project background, problem statement, objectives and scopes of this report.

Chapter 2 – Literature Review

This chapter review on the concept of coupled tank system, PID controller, PID tuning and others reviews related to this project.

Chapter 3 – Methodology

This chapter presents the flow of the study and method being used in this study. MIMO coupled tank system model and mathematical modeling of MIMO coupled tank system; the parameter value will be discussed in this chapter.

Chapter 4 – Result

This chapter shows results performance of the system using two types of controller using MIMO PID controller; between Cuckoo Search and Particle Swarm Optimization.

Chapter 5 – Conclusion

This chapter consists of conclusion of overall works and result.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter described about conceptual and previous past research on project of Multi-Input Multi-Output Coupled Tank System and PID tuning using optimization technique that related to this research paper.

2.2 Coupled tank system

Tank level control systems are easily found in our daily life. Generally many process and system depends on the tank level control systems such as industrial process, the human body and fluid handling system [1]. In the process industries, controlling the liquid level and flow between tanks is a common major issue. The process industries require liquids to be pumped, stored in tanks and pumped to another tank. The level fluid in tanks must be controlled and the flow between tanks must be regulated [1].

In understanding the principle of liquid level and flow control coupled tank has been used as the part of the studies which is Coupled-Tank Model CTS 001 as shown in Figure 2.1. This equipment is jointly designed with Kent Ridge Instrument (Singapore) Pte. Ltd [3]. It is a computer-controlled coupled tank system that is used for liquid level control [2].

Figure 2.1: CTS-001

It consists of a Perspex tower-type tank mounted above a reservoir which functions as storage for water. The large tank is divided into two smaller tanks by a baffle plate in the center. The baffle plate can be adjusted for inter-tank flow, varying the coupling dynamic [3]. There are two types of coupled tanks system which are Single input – single output (SISO) Coupled tanks system (CTS) and Multi input – Multi output (MIMO) Coupled tanks system (CTS). Basically, coupled tank consists of two tanks connected each other by a flow channel. It makes the level of liquid in each tank to interact. Each tank has its own pump to inflow liquid.

For the SISO coupled tank, it is divided into two categories which are a first order coupled tank system and second order coupled tank system. Based on Figure 2.2, the first order coupled tank system consists one tank which involves one input, Qi and one output, Qo. While for the second order coupled tank system as shown in Figure 2.3, it consists the combination of tank 1 and tank 2 where the input is at tank 1, Qi and the output at tank 2, Qc. The concept or how the both tank works are same. SISO coupled tank used one controller to control the flow rate of water of the tank.

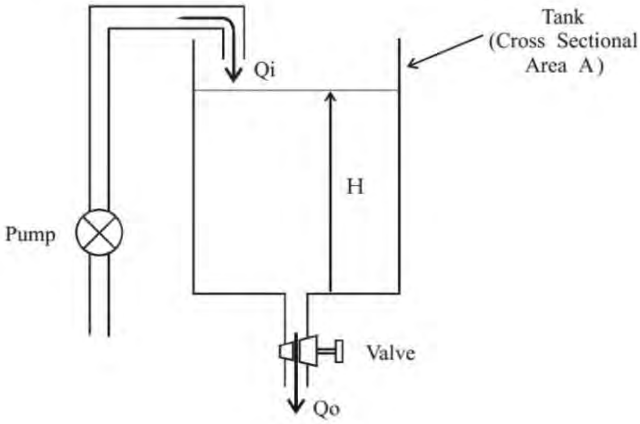

Figure 2.2 : First order coupled tank system

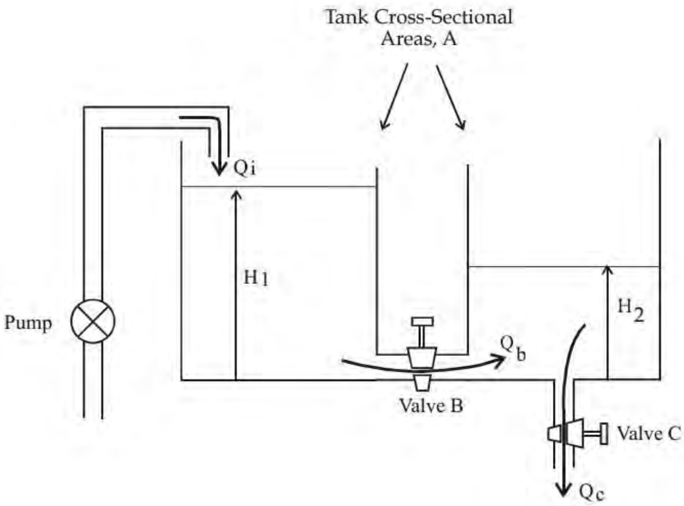

Figure 2.3 : Second order coupled tank system

Where:

H1, H2 = height of water in tank 1 and tank 2

Qi = pump flow rate into tank

Qb = flow rate of water between tanks

Qc = flow rate of water out of the tank

Meanwhile, for the MIMO CTS, it is different from the SISO tank. This is because the MIMO CTS consists of two inputs and two outputs. In other word, tank 1 consists of one input, Qi1 and one output, Qo1 while tank 2 also consists of one input, Qi2 and output, Qo2. The level of both tank are controlled by a valve which is connected between tank 1 and tank 2. Each tank has its own controller, which mean that controller 1 control the flow rate of water of tank 1 and controller 2 control the flow rate of water of tank 2.

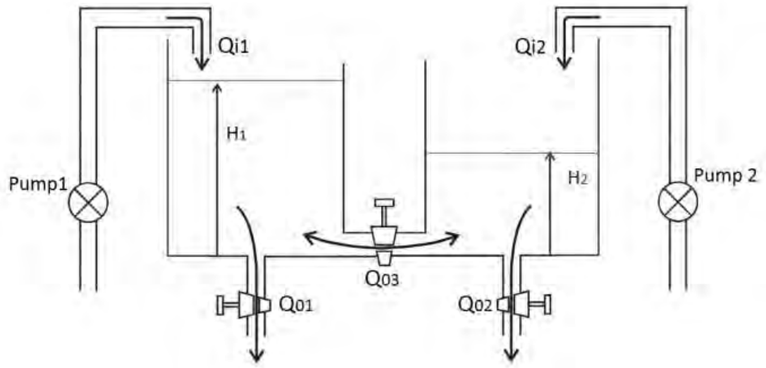

Figure 2.4 : MIMO Coupled Tank System

Where:

H1, H2	= height of water in tank 1 and tank 2
Qi1, Qi2	= pump flow rate into tank
Qo1, Qo2	= flow rate of water out of the tank 1 and tank 2
Qo3	= flow rate of water between tank

2.3 PID Controller

A proportional-integral-derivative controller (PID controller) is a most common form of feedback control widely used in industrial control systems. This due to their simplicity, robustness and successful practical application [20]. It used to calculate an error which is the value difference between a measured variable and a desired set point. In other word, PID attempts to minimize the error by adjusting the process through use of a manipulated variable. PID control is often combined with logic, sequential function, selectors, and simple function blocks to build a complicated automation system used for energy production, transportation and manufacturing as in [4].

The PID controller algorithm is combination of three-term control; the proportional, the integral and derivative values, denoted as P, I, and D. The general equation or the final form of PID algorithm is;

$$u(t) = K\left(e(t) + \frac{1}{Ti}\int_0^t e(\tau)d\tau + Td\,\frac{de(t)}{dt}\right) \quad (2.1)$$

$$u(t) = K_P + \frac{1}{s}K_I + K_D s \quad (2.2)$$

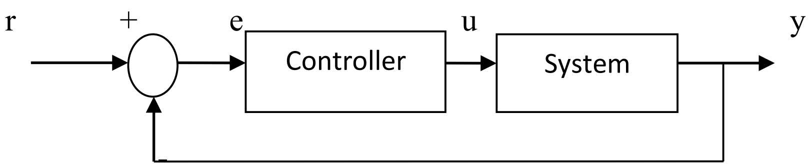

Figure 2.5 : PID Block Diagram

Based on the Figure 2.5, y is the measured process variable, r the reference variable, u is the control signal and e is the control error. Reference variable also called the set point. The controller parameters are proportional gain K, integral time Ti, and derivative time Td.

An output value that is proportional to the current error value is produced by the proportional term. Multiplying the error by a constant Kp, called the proportional gain constant can adjusted the proportional response. For the integral term, it used to eliminate the residual steady state error that occurs with a proportional controller. Derivative used to damp oscillations. In other words, it improves settling time and stability of a system.

2.4 PID Tuning

The original technology for industrial PID controllers was analogue, and these controllers usually had a simple interface for manually tuning the controller [5]. There are two parts to tuning which are how to choose the structure of the PID controller and how to choose the numerical values for the PID coefficient or tune the controller. The purpose of PID tuning is to find the best and proper value for K,Ki and Kd. In other words is to make the system response become faster with good stability.

Table 2.1 : Tuning effect of the PID controller terms

	Reference tracking tuning Step Reference		Disturbance rejection tuning Constant load disturbance	
	Transient	Steady State	Transient	Steady State
P	Increasing Kp>0 speeds up the response	Increasing Kp>0 reduces but does not eliminate steady state offset	Increasing kp>0 speeds up the response	Increasing kp>0 reduces but does not eliminate steady state offset
I	Introducing integral action Ki>0 gives a wide range of response types	Introducing integral action Ki>0 eliminates offset in the reference response	Introducing integral action Ki>0 gives a wide range of response types	Introducing integral action Ki>0 eliminates steady state offsets
D	Derivative action Kd>0 gives a wide range of response and can be used to tune response damping	Derivative action has no effect on steady state offset	Derivative action Kd>0 gives a wide range of responses and can be used to tune response damping	Derivative action has no effect on steady state offset

2.5 Optimization technique

In optimization of a design, the configuration goal could be basically to minimize the expense of generation or to amplify the productivity of creation [6]. An optimization algorithm is a produce which is executed iteratively by contrasting different arrangements till an ideal or an attractive arrangement is found. In other word, it is a process to find the best way in order to achieve desirable outcomes [8]. There are two unique sorts of optimization algorithm broadly utilized today which are deterministic algorithm and stochastic algorithm. Deterministic algorithm use specific rules for moving one solution to other. These algorithms are in use to suite some times and have been successfully applied for many engineering design problem. The stochastic algorithms are in nature with the probabilistic translation rules. There is gaining popularity due to certain properties which deterministic algorithms do not have.

Meta-heuristic have been established as a standout amongst the most viable methodology to simulation optimization [7]. The applicability of meta-heuristic as a favored strategy over other optimization methods is essentially to discover great heuristic answers for complex streamlining issues with numerous nearby optima and minimal inalienable structure to guide the inquiry. The meta-heuristic methodology to tackling such issue is to begin by getting a beginning arrangement or a starting set of arrangements, and afterward starting an enhancing pursuit guided by specific principles.

There are various types of optimization techniques which are classified under meta-heuristic techniques. Most of them are inspired by nature or animal behavior [9]. One of the earliest meta-heuristic is simulated annealing (SA). It was presented by Kirkpatrick, Gelatt and Vechhi in 1983 [7] and its working standards are focused around the procedure of progressive cooling of metals in nature [9]. Genetic algorithm (GA) developed by John Holland in 1960's and 1970's [10]. It based on natural selection and solve complex problem [9]. Artificial bee colony (ABC) is based on the simplified models of the food searching behaviors of the bee-swarms [11]. Particle swarm optimization (PSO) is a population based stochastic and multi-agent parallel global search technique [11]. Cuckoo search (CS) is proposed by Yang and Deb in 2009. It is based on brood parasitism behavior of some cuckoo species [13].

2.6 Cuckoo Search and Particle Swarm Optimization

Cuckoo search (CS) is one of the latest nature-inspired meta-heuristic algorithms, developed by Xin-She Yang in 2009 [10]. Cuckoo is a fascinating birds, this due their aggressive reproduction strategy. Some birds when they lay their eggs in the nest, the will remove other eggs to increase the hatching probability of their own eggs. Different from cuckoo it will lay one eggs at others bird (host species) nest. Their eggs will hatch faster the host species eggs. The egg laid by a cuckoo is discovered by the host bird with the probability$\rho_a \in (0,1)$ [13]. Some host bird might throw if they found there is another egg in their nest or abandon the nest to build a new nest somewhere else. This reduces the probability of their egg being abandoned and increased their reproductively.

Particle swarm optimization (PSO) is developed by James Kennedy and Russell Eberhart in 1995. It is inspired by the social behavior of bird flocking and fish schooling [14]. It utilizes a population of particles that fly through the problem hyperspace with given velocities [14]. A flock animal that have no leaders will find the food by random which means when one of the animal found a food then the others will follow. The food represents the potential solutions of a problem. PSO as developed by James Kennedy and Russell Eberhart comprises a very simple concept, and paradigms can be implemented in a few lines of computer code [15].

Recent studies show that CS is potentially more efficient than PSO and genetic algorithms [13]. Other than that, the optimal solutions obtained by CS are better than the best solutions obtained by an efficient PSO [12].

2.7 Past Research

Several research have been done in previous research which involve the application of coupled tank system. The first one is Liquid Level Control of Nonlinear Coupled Tanks System Using Linear Model Predictive Control. The purpose of this research is to make a comparison usage of discrete time linear model predictive in controlling a nonlinear coupled tank system between Generalized Predictive Control and Laguerre Functions. Model Predictive Control (MPC) refers to a specific procedure in controller design from which of many kinds of algorithms can be developed for different systems, linear or nonlinear, discrete or continuous [17]. The system performance of both controllers were investigated when used to control SISO CTS and MIMO CTS. As the result, MPC using Laguerre function performs better than MPC using GPC. This due to MPC using Laguerre functions reduces computational cost.

The next past research is Robust MIMO Water Level Control in Interconnected Twin-Tanks Using Second Order Sliding Mode Control. Sliding mode control (SMC) is known to be a robust control method appropriate for uncertain systems. High robustness is maintained against various kinds of uncertainties such as external disturbances and measurement error [18]. Coupled tank system has been modelled and comparison between simulation study and experiment were made. The main purpose of this research is to prove that the proposed theory of the system model is correct by implements the real experiment of the system.

The third previous research is A Type-2 Fuzzy Logic Controller for the Liquid-Level Process. Fuzzy logic is a form of logic whose underlying modes of reasoning are approximate instead of exact and emulates the ability to reason and use approximate data to find solutions [19]. The focus in this study is to examine the system performance between two types of fuzzy logic controller which are type-1 FLC and type-2 FLC. Both were evolved by a genetic algorithm (GA) to control a liquid process level. As the result, Type-2 FLC is better compare to type-1 FLC in designing the controller for coupled tank system. This due to the type-2 FLC ability to eliminate persistent oscillations and Type-2 FLC more robust than type-1 because it can tolerate bigger modelling error.