ROBUST PID CONTROLLER FOR CONTROLLING DESIRED LEVEL OF COUPLED TANK SYSTEM

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DECLARATION

I declare that this thesis entitled "ROBUST PID CONTROLLER FOR CONTROLLING DESIRED LEVEL OF COUPLED TANK SYSTEM" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date	:	3 JULY 2021

APPROVAL

I hereby declare that I have checked this report entitled "ROBUST PID CONTROLLER FOR CONTROLLING DESIRED LEVEL OF COUPLED TANK SYSTEM''and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : TS. DR. HAZRIQ IZZUAN BIN JAAFAR

Date : 5 JULY 2021

DEDICATIONS

To my beloved mother and father for always support me and being my motivation in the journey of my study

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"In the name of Allah the Most Gracious, the Compassionate Merciful"

Alhamdulillah praise to Allah the owner of the knowledge for giving me the guidance to finish my Final Year Project. I would never able to complete my project without His permission and blessings.

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ABSTRACT

Coupled Tank System (CTS) is mostly used as the operational tools to store and transfer the liquid in the chemical industries. The performance control of the water level in the CTS is a vital aspect to be encountered to ensure the industries or company's production are in good phase. Thus, a suitable control system needs to be implemented in the CTS. The objectives of this project are to study the PID tuning techniques in terms of their performance of rise time (T_r), peak time (T_p), settling time (T_s) and the percentage of overshoot (%OS). Besides this project also aims to determine the best tuning technique in the PID controller to control the liquid level of CTS. Lastly, to observe the effectiveness of the optimal PID controller under various input tracking (robustness) for CTS. Four conventional techniques of PID tuning method such as Ziegler-Nichols (Z-N), Cohen-Coon (C-C), Trial and Error (T-E), and Auto Tuning (A-T) are chosen for CTS. For the Z-N and C-C methods, a manual calculation is implemented to obtain the parameter value for the PID controller. For the optrimization technique, Particle Swarm Optimization (PSO) algorithm is chosen as the PID parameters searcher. The CTS system is simulated by using the MATLAB/Simulink software. The robustness of the system is also tested by applying the various input of water level. As a results, PSO method is found to be the best tuning method among the tuning techniques.

ABSTRAK

Sistem Tangki Berkembar (CTS) selalunya digunakan sebagai alat pengoperasian untuk menyimpan dan menyalurkan cecair dalam industri kimia. Prestasi kawalan aras cecair di dalam CTS sangat penting demi memastikan pengeluaran hasil industri dan syarikat dalam fasa yang baik. Oleh itu, sistem kawalan yang bersesuaian perlu untuk diterapkan di dalam CTS. Objektif bagi projek ini adalah untuk mengkaji teknik penalaan dalam konteks prestasi bagi masa kenaikan (T_r)*, waktu puncak* (T_p)*, masa diambil untuk mendatar* (T_s)*, dan peratusan lebihan (%OS). Selain itu, projek ini juga bertujuan untuk mengenalpasti teknik penalaan yang terbaik dalam pengawal PID untuk mengawal aras cecair di dalam CTS. Akhir sekali, projek ini bertujuan untuk memerhati keberkesanan pengawal PID optimum dengan masukan yang pelbagai (ketahanan) dalam CTS. Empat jenis pengawal PID konvensional yang terdiri daripada Ziegler-Nichols (Z-N), Cohen-Coon (C-C), Percubaan dan Kesilapan (T-E), dan kaedah Penalaan-Sendiri (A-T) dipilih untuk CTS. Untuk kaedah Z-N dan C-C, pengiraan secara manual akan digunakan untuk mendapatkan nilai parameter bagi pengawal PID. Bagi kaedah teknik pengoptimuman, algoritma Pengoptimum Kerumunan Zarah (PSO) telah digunapakai untuk mendapatkan nilai parameter bagi pengawal PID. Sistem CTS disimulasikan dengan menggunakan perisian MATLAB/Simulink. Ketahanan sistem juga akan diuji dengan mengaplikasikan masukan aras cecair yang pelbagai. Hasilnya, teknik PSO telah dibuktikan merupakan kaedah terbaik di antara teknik-teknik penalaan yang lain.*

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CHAPTER 1

INTRODUCTION

1.1 Background

In control engineering, the controller is the fundamental part of a system that control the performance quality of a system by measuring an error signal and adjusting the system to the desired level of the expected outcome. It is done by improving the steady-state accuracy by decreasing the steady-state error. Controllers also help in reducing the unwanted offsets produced by the system. Nowadays, a control system is applied in most industries including automotive, manufacturing, water treatment plant, and petrochemical plantation.

The most widely used application in the industrial process is the Coupled Tank System (CTS). This system is developed to control the liquid level in both tanks simultaneously. The liquid in the tanks must be maintained at a certain volume to fulfill the requirement of a factory or industry. The common problem in process industries is to control the liquid storage tanks and chemical blending. A stable and constant rate of desired liquid level can be achieved by regulating the flow of liquid in and out of the tank [1].

To control the level of the liquid to the desired level, a suitable controller need to be installed. The commonly used controller for the system is Proportional-Integral-Derivative (PID), Proportional-Integral (PI), Proportional-Derivative (PD), Fuzzy Logic Controller (FLC), Sliding Mode Control (SMC) and Linear Quadratic Regulator (LQR). However, many industries much preferred to use the PID controller due to simple and easy to implement [2]. There are two tuning approaches in the PID controller which are known as conventional technique and optimization technique.

1.2 Reseach motivation

PID controller has been extensively used in the industries because of its feasibility and easy to be implemented. PID also a flexible controller where the PID gains can be designed based upon the system parameters if they can be achieved or estimated precisely. There several tuning methods for obtaining appropriate control parameters such as Ziegler-Nichols (Z-N), Cohen-Coon (C-C), Trial and Error (T-E), and Auto Tuning (A-T) [2]. Tuning methods are very important in a control system to obtain the best performances and robustness by adjusting the value of the parameters.

1.3 Problem Statements

There are few problem statements for this project as listed below:

i. More effort is needed to obtain optimal PID controller parameters as the best tuning approach.

ii. A lot of mathematical approaches need to be considered to fulfill the requirement of process control.

iii. Difficult to obtain the stable results for the best performance of transient response.

1.4 Research Objectives

The main objectives to be achieved for this project are:

i. To simulate PID controller parameters based on existing conventional methods for CTS.

ii. To implement Particle Swarm Optimization (PSO) algorithm in determining the optimal parameters of PID controller.

iii. To observe the effectiveness and robustness of the optimal PID controller under various input tracking

1.5 Scope of Research

Several scopes need to be considered to fulfill the project objectives which are:

i. Apply the established modeling of Coupled Tank System (CTS) referring to the previous research.

ii. Apply the conventional PID controller techniques (Z-N, C-C, A-T, and T-E) and the optimizational tuning technique (PSO) to obtain the parameters of CTS.

iii. Simulate the model of CTS with the PID controller model in MATLAB/Simulink software.

iv. Analyze the performance of each PID controller method in terms of transient response to determine the best tuning method.

v. Compare and contrast the robustness of the PID control techniques by injecting the various input signal for both conventional and optimizational method.

1.6 Organization of Research

The organization is separated by chapter which are:

- **Chapter 2, Literature Review:** This chapter will describe the fundamental backgrounds of the CTS and control system.
- **Chapter 3, Methodology:** This chapter will propose the methodology of the project and also discuss the flow of the project.
- **Chapter 4, Result and Discussion:** This chapter will show the preliminary result based on the simulation done in Chapter 3.
- **Chapter 5, Conclusion and Recommendation:** This chapter will give a summary of the project done whether the objective is achieved or not and will state the improvise for the future project that needs to be done.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter generally explains the overview of the system, mechanism, and overall concept of this project. The explanation includes the theoretical background, clarification of tuning techniques being applied, and also the comparison between the techniques.

2.2 Coupled Tank System (CTS)

The equipment type CTS-001, CTS, is intended for the 2 tanks (Tank one and Tank 2) anywhere the water storage referred to as a reservoir is finished at its lowest. Each of the tanks is fitted with a capacitive-type probe to rapidly pump the water level up to the highest of each tank with 2 independent pumps [2]. The pumps move the water from the bottom basin before to the machine that is completely installed with an outlet for each tank, near the basin, and a plastic hose connects this outlet. The amount of water returned to the reservoir is roughly equal to the water level in the reservoir, as the plastic water-return tube at the reservoir basin acts as a pseudo-linear hydraulic resistance [3]. The standard DC output voltage activity is within the range of 0 ± 5 Volts for which, when the tanks are empty, the zero degrees reflect the remainder of the water (approximately 20 mm). The water level then starts to run through the rear plastic standpipes at roughly 270 mm. The ability to direct water flow along with variable outflow orifices enables many interesting combinations of Single Input Single Output (SISO). It is called multiple input multiple output experiments (MIMO) because there are two or more CTS that can be mixed together. The MIMO is the various ways in which the device has been set up with another valve to develop CTS that enables fluids to exit the bottom of Tank 1 and another Tank 2 pump supply fluid.

2.3 Type of Controller in CTS

In previous research related to CTS, such as Fuzzy Logic Controller (FLC), Proportional Integral (PI) controller, Proportional Derivatives (PD) controller and PID controllers, a few controllers have been developed and implemented. The PID controller, however, is the most famous approach to the realistic control issues typically used in the industry.

2.3.1 Fuzzy Logic Controller

FLC is a traditional intelligent control technique that has been used as a fuzzy Logic calculator for PID parameter tuning [4]. A standout of the best fuzzy set of uses in which, as opposed to numeric, variables are semantic.

Lotfi Zadeh, the first researcher to present the FLC, introduced a set theory in 1965 that aimed at people's actions in making decisions based on imprecise and non-numerical evidence. The theory called fuzzy sets explained the problems of crisp sets and solved them. Instead of 'true' or 'fake', 'yes' or 'no', '1' or '0' only, it is possible to grant a degree membership from '0' to '1' to a range [5]. A 4-stage FLC framework is built (fuzzification, inference, information, knowledge base, and defuzzification) that to convert input signals through sensor readings as output signals, the change in the control input (Δu). Fuzzification is the translation of input signs, error readings (e), and error rate changes (Δe) into the respective fuzzy values. The fuzzy (e and Δe) would be based on the information or rule base, determine either a basic rule or guidelines for an inferencing algorithm to be fired. Signals from inference stages will then flow inside the defuzzification system to turn it into one crisp (Δu) value. As seen in Figure 2.1, a schematic of the FLC system is visualised.

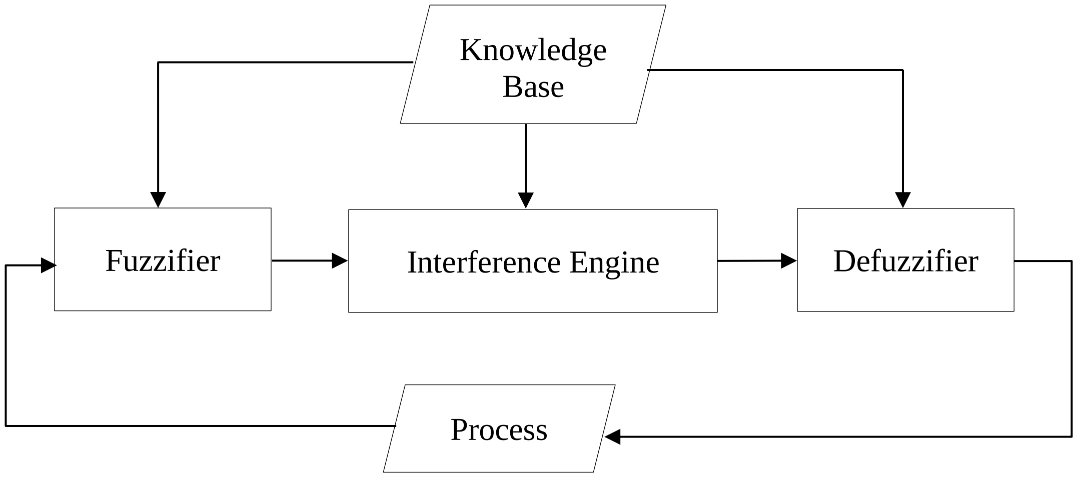

Figure 2.1The block diagram FLC system [5]

2.3.2 Proportional Integral Controller

For non-integrating systems, the PI controller is applied, meaning any process that ultimately returns to the same output due to the same collection of inputs and disturbances. PI controller is a feedback control loop that equals the sum of proportion and integration coefficients to measure an error signal and eradicate it with the output power. This is because the output system can never continue to remove the system's steady-state error, but can stabilize the dysfunctional mechanism by using single energy storage first-order processes [6]. The looping mechanism can be shown in Figure 2.2.

This controller is normally used where the speed of the mechanism is not a concern because it has a negative effect on the speed and overall reaction stability. The output response does not decrease in rising time, but it can also not remove the oscillations. Furthermore, the PI controller has not been able to predict possible device failures or errors, but it can improve the damping ratio. In CTS, the PI controller is implemented to obtain *Kc* and *Ki* gains and compared to the best output by four separate tuning methods, namely pole placement, Ciancone, modified Z-N, and C-C methods [6].

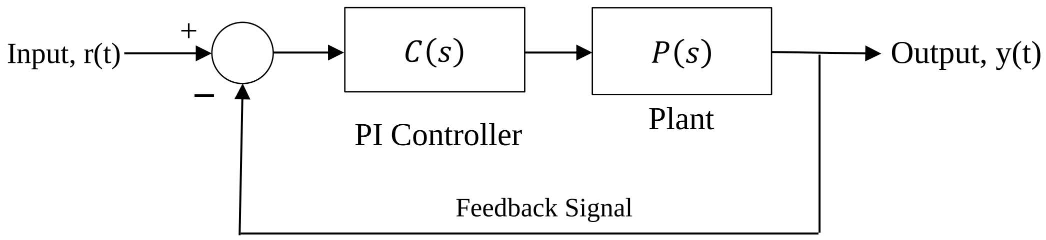

Figure 2.2Closed-loop of PI controller

2.3.3 Proportional Derivative Controller

Derivative controllers respond to changing error signals but do not, however, respond to constant error signals, since the rate of shift of error over time is zero with a constant error [7]. Owing to this, derivative control D and proportional control P are merged resulting Proportional Derivative controller (PD). This concept can be expressed mathematically as below:

$$\text{PD Controller output} = (Kp \times error) + (Kd \times rate\ of\ change\ of\ error)$$

The performance of the controller will differ with proportional plus derivative control when there is a continuously changing error. Because of the derivative action accompanied by the incremental adjustment due to proportional action, there is an initial rapid change in controller output. In this way, this type of control will cope easier with accelerated process shifts than just proportional control alone. It also needs a steady-state error, much like proportional control alone to deal with a continuous change in input conditions or a change in the fixed value. Therefore, better than just proportional control alone, PD control can deal with accelerated process shifts. In order to deal with a continuous change in input conditions or a change in the set value, it also needs a steady-state error [7].

2.3.4 Proportional Integral Derivative (PID) Controller

For the last six decades, PID controls have been commonly used in industrial practice. The invention of PID control was in 1910 (mainly attributed to the autopilot ship of Elmer Sperry) and the straightforward tuning law of Z-N in 1942 [8]. PID controllers are widely used in many industries such as papermill, cotton textile industries [9]. In more than 90% of practical control systems, PID is used today, ranging from consumer electronics such as cameras to manufacturing processes such as chemical processes. The role of the PID controllers is to keep the output at a level where there is no difference (error) in the fastest response possible between the method variable and the set point.

In level control, the controller's task is to retain a level fixed point at a specified value and be able to dynamically consider new set point values [10]. Via electrical tubing, transistors and integrated circuits, PID controllers have undergone numerous technical developments, such as mechanics and pneumatics for microprocessors. This has created opportunities to deliver additional capabilities such as adaptive tuning, continuous adaptation, and PID controller scheduling. The basic PID block diagram can be shown in Figure 2.3:

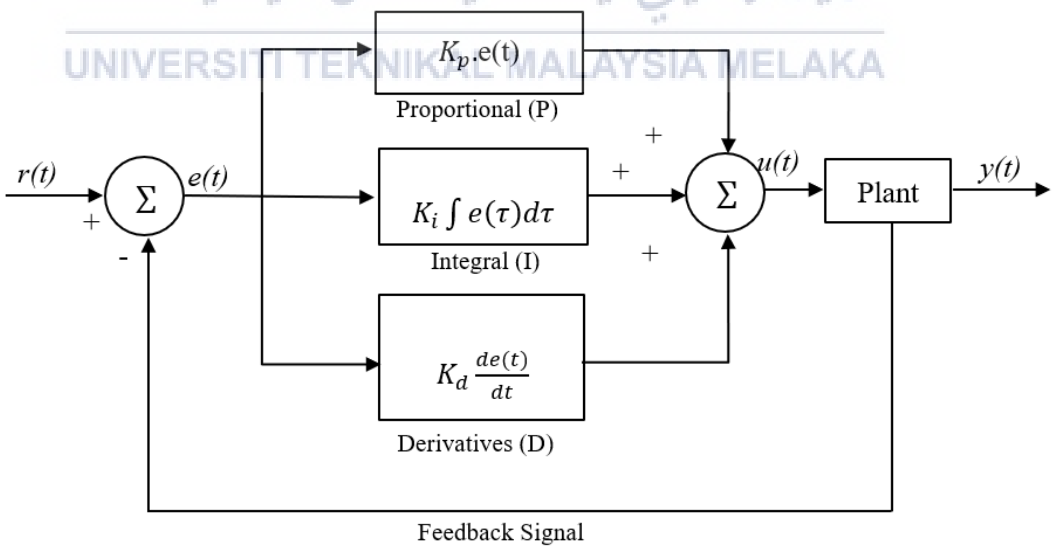

Figure 2.3 PID controller looping system [11]

The PID controller loop system is also known as a feedback control system, and this type of system is used to construct the desired output or reference system to be automatically stable. It produces an error signal for this purpose. The error signal *e(t)* is a differentiation between the output *y(t)* and the reference signal *u(t).* When this error is zero, the desired output is obtained and the output is the same as the reference signal in this condition. The PID controller consists of three-term control which is Proportional (P), Integral (I), and Derivative (D). Each term control affects the performance of the system which is the Rise Time (Tr), Settling Time (Ts), Steady State Error (SSE), and the percentage of Overshoot ($0S$%).

The 'P' word is proportional to the error's real value. The control output is also large if the error is large and the control output is also minimal if the error is small, but the gain factor (K_p) is also taken into account. Reaction speed is therefore directly proportional to the proportional gain factor (K_p). Thus, by changing the value of (K_p), the reaction speed is increased, but if K_p is increased above the normal range, the process variable continues to oscillate at a high rate and makes the system unstable.

Generally, the integral controller is used to reduce the error of the steady-state. The expression 'I' is inserted into the actual value of the SSE (with respect to time). The extremely small value of error, due to convergence, results in a very large integral response. Until error becomes zero, integral controller behavior begins to shift. Integral gain is inversely proportional to response speed, increasing K_i, decreasing response velocity. Proportional and Integral controllers are used combined (PI controller) for good speed of response and steady-state response.

The derivative controller is used for PD or PID combinations. It is never used alone, so the output of the controller would be zero if the error is constant (non-zero). In this case, the controller has a zero-life error, but there is some error in fact (constant). As seen in the equation, the output of the derivative controller is directly proportional to the rate of change of error with respect to time. We get a constant derivative advantage by removing signs of proportionality by excluding (K_d).

2.4 Tuning Techniques

Closed-loop process control to assess the optimal gain of Kp, Ki, and Kd which is known as PID controller tuning. Different tuning methods have been used to achieve the optimal response from a control system. There are types of tuning techniques, which are conventional and optimization techniques that are categorized into 2 main tuning techniques.

2.4.1 Conventional Technique

Generally, there four types of the conventional technique applied in the industries and also for the academic purposes, which is Z-N, C-C, T-E and A-T. These four techniques are applicable in the CTS to control the behavior of the liquid level. Conventional controllers can produce quite comparable with advanced controllers for problems of robust performance of relevant interest in process control [12].

The Z-N is developed by John G. Ziegler and Nathaniel B. Nichols. This tuning method is applied to require the system process to be stable. Z-N method is the first PID tuning techniques developed and they are rendered based on certain assumptions of the controller. Therefore, more tuning is often needed because the derived controller settings are very aggressive and therefore result in excessive overshoot and unstable responses. In this tuning process, K_i and K_d gain is set to zero at for the starting. K_p is then raised until the ultimate gain, K_u, at which the loop output continues to oscillate in the oscillation cycle, T_u, is obtained [2].

The next method is C-C. his approach is very similar to Z-N, where the parameters of the controller are only obtained by a particular method. This method can only be achieved in the open-loop system, while in the open and closed-loop system, Z-N can be obtained. There are a few pros and cons of these two methods. Even though Z-N is the most widely used tuning controller, C-C has its advantage which is C-C method is more flexible compared to the Z-N tuning method. The Z-N method works well only on the processes where the dead time is less than half the length of the time response compared to the C-C method where the dead time is less than two times the length of the time constant.

A-T technique is the easiest method among conventional techniques. This method is applied directly from the MATLAB/Simulink where one just has to set up the PID Tuner App and plug in the parameters needed. Lastly, the most classical method is the T-E method. However, it requires time and experience in order to achieve the optimum result. In this method, the value of K_p, K_i, and K_d must be set to zero in this method. Then until the output of the responses oscillates, the K_p is increased. As the relative gain increases, the processes can become unstable, and countermeasure is required to prevent the system from being unreliable. K_i is elevated so that it can interrupt oscillations when the K_p is adjusted to get the desired fast response. This approach can be applied by using the command tool provided in MATLAB Software.

2.4.2 Optimization Technique

Instead of conventional methods, optimization techniques are now well-positioned in the industry. The method of optimization is used to minimize cost and energy consumption or to optimize productivity, profit, output, and development. This method offers tremendous promise based on previous studies and is very versatile and resilient relative to its predecessors. Also, the optimization formulation seems to be numerically robust, since convergence was achieved in all studied cases.

Moreover, it is important to point out that not all the potentiality of the method was used. It also found that the optimization method treats the errors modeling well enough and by considering constraints in the process variables, in the movements of the manipulated variable, and the overshoot. Moreover, the optimization method can be applied to several types of controllers [13]. Genetic Algorithm (GA), Firefly Algorithm (FA) and Cuckoo Search Algorithm (CSA), are different types of optimization techniques.