LIQUID LEVEL CONTROL OF A COUPLE TANK SYSTEM BASED ON SMOOTH TRAJECTORY TRACKING USING PID CONTROLLER

SALMAN BIN RAZENI

This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Control & Instrumentations)

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Signature : ______________________________

Author : SALMAN BIN RAZENI

Date : 24 NOVEMBER 2008

"I hereby acknowledge that the scope and quality of this thesis is qualified for the award of the Bachelor Degree of Electrical Engineering
(Control & Instrumentations)"

Signature : ______________________________

Name : MOHD SYAKIRIN BIN RAMLI

Date : 24 NOVEMBER 2008

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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 Proportional-Integral-Derivative (PID) controller in controlling the liquid level in the second tank of Coupled-Tank plant through variable manipulation of water pump in the first tank. This project presents the ability of controlling the liquid level of a coupled tank system that used Programmable Logic Controller (PLC) as a main controller hardware. A PID controller has been developed and designed via ladder programme of CX-programmer. A mathematical model of the couple tank system was derived by refering to the experimental manual and verified by using MATLAB software. The controller parameters derived from the simulation and design process using MATLAB as well. The project is based on Single Input Single Output (SISO) system which mean the liquid will entering the tank 1 (pump 1) in couple tank while the level control is in tank 2 in the condition of pump 2 is set OFF. The aim of the project is to design controller that can maintain the level and minimize the error (SP-CV) value at any of given set point(SP). It is to show that PID controller could produce appropriate control signal to the coupled-tank system and minimize the error value for the system. A series of tracking performance tests conducted to evaluate the controller performance in comparison to other controller such are fuzzy controller, DMRAC controller or other controller that used by other reearcher before. . The outcome of the project reveals that PID controller could carry a small error rate when the appropriate value of K_p, K_i, and K_d are applied. The framework of this project is generic enough to have an overview of the possible outcome before implementing the PID controller in real-time system in the future.

ABSTRAK

Industri seperti industri petro-kimia, industri pembuatan kertas, pengurusan sisa dan lain adalah industri penting di mana kadar cecair dan kawalan aliran adalah penting. Cecair akan diproses dengan mencampurkan bahan kimia atau perlakuan dalam tank, tetapi tahap cecair di dalam tangki harus dikawal, dan aliran antara tank harus diatur. Projek ini menyiasat penggunaan “ PID) controller “ dalam kawalan tahap cecair di kedua tangki melalui manipulasi pembolehubah pam air pertama tangki. Ini adalah untuk menunjukkan bahawa PID boleh menghasilkan isyarat kawalan yang sesuai kepada sistem tangki dan meminimumkan nilai kesalahan sistem. Sebuah model dinamik tanaman awalnya dikembangkan. Simulasi pengajian kemudian dilakukan berdasarkan model yang dikembangkan dengan menggunakan Matlab dan Simulink. Ujian yang dilakukan untuk menilai prestasi pengawal berbanding dengan kaedah kawalan lain adalah seperti kaedah pengendali fuzzy, DMRAC atau pengendali lain yang digunakan oleh penganalisa lain terdahulu. Keputusan daripada projek menunjukkan bahawa PID boleh membawa tingkat kesalahan kecil ketika nilai yang sesuai Kp, Ki, dan Kd diterapkan. Rangka projek ini adalah cukup umum dan mempunyai keputusan yang mungkin berbeza sebelum pelaksanaan PID pada masa yang akan datang.

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LIST OF SYMBOL

Kp	-	Proportional gain
Ki	-	Integral gain
Kd	-	Derivative
Kcr	-	The first value of Kp when the output exhibits sustained oscillation
Pcr	-	A time for one cycle at the graph when Kp = Kcr
A	-	Ampere
V	-	Voltage
T_i	-	Integral Time
T_d	-	Derivative Time
Ts	-	Sampling Time

LIST OF ABBREVIATION

PID	-	Proportional Integral Derivative
PLC	-	Programmable Logic Controller
AI	-	Analog Input
AO	-	Analog Output
I/O	-	Input/Output
PV	-	Process Variable
SP	-	Set Point
CV	-	Controlled Variable
E	-	Error

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CHAPTER 1

INTRODUCTION

1.1 Research 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.

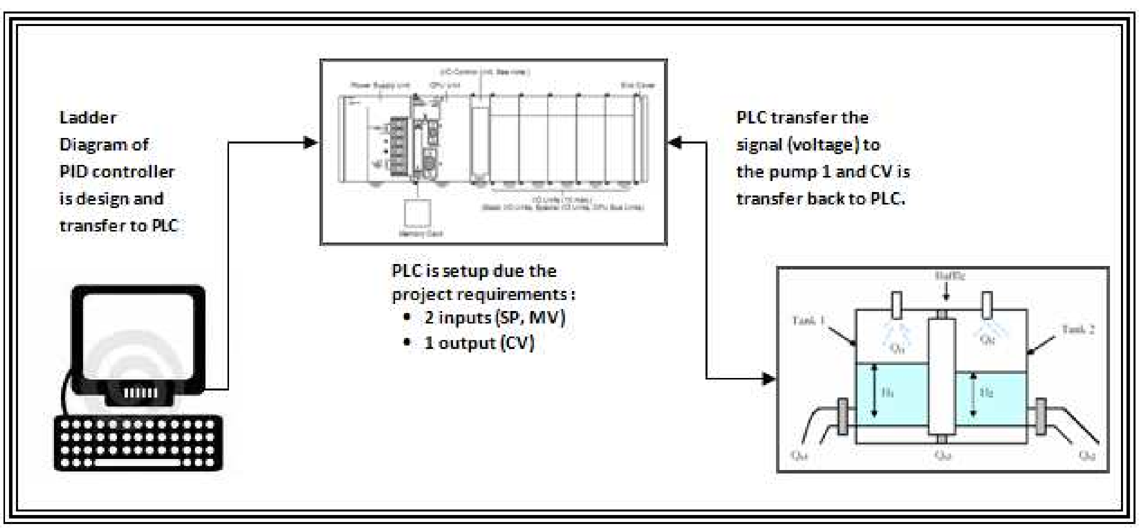

Figure 1.1 : Project overview (in term of diagram)

The aim of this project is to control the liquid level in tank 2 of the Coupled Tank Liquid Level System based on a smooth trajectory tracking using the PID controller. This project will implement Proportional-Integral-Derivative (PID) controller algorithm (for controlling liquid level in couple tank system) perform by PLC. The controller algorithm that has been chosen is Proportional-Integral-Derivative (PID) controller while the plant or system used is the coupled tank system.

An algorithm will be programmed in PLC via CX-programer software where it will generate a smooth trajectory signal send to the couple tank after execution process. The system will also shows the relation between PLC, PC (software development, interface) and couple tank liquid system itself in term of controlling the liquid level. PID control mode is shown in figure 1.2 below.

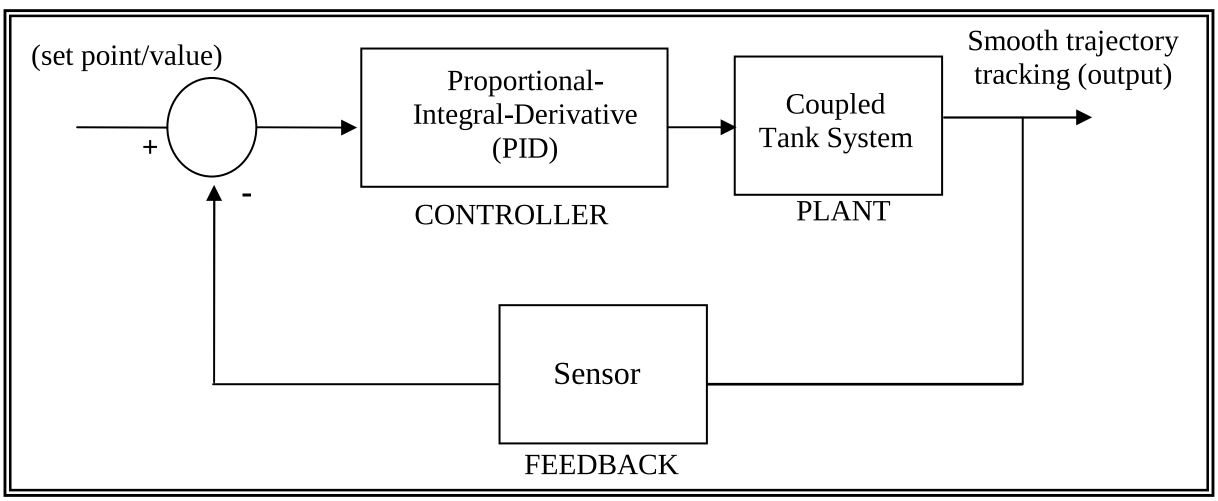

Figure 1.2: Proportional-Integral-Derivative (PID) Control Model

1.2 PID controller

Proportional-Integral-Derivative (PID) controllers are still widely used in industrial systems, despite the significant developments of recent years in control theory and technology. This is because they perform well for a wide class of processes. Also, they give robust performance for a wide range of operating conditions. Furthermore, they are easy to implement using analogue or digital hardware and familiar to engineers.

The proposed controller has three parameters to be adjusted. This can often be done easiIy by trial and error or by using one of many tuning rules. In the conventional PID control algorithm, the proportional, integral and derivative parts are placed in the forward loop, thus acting on the error between the set point and closed loop response. This PID controller implementation apart from the derivative kick, which occurs if a step change takes place in the set point, is suitable for control of stable processes with small time delays. However, it is well known that for processes with resonances, integrators and unstable transfer functions, difficulties are encountered.

1.2.1 *PID characteristics*

Proportional action is the simplest form of continous control, producing a ontrol output that is directly proportional (by an amplifying factor K) to the error input, for example K=5 (five times greater).

Output = (*K*) **X** (*error signal)*

However, proportional action is rarely sufficient in itself because, as the system output approaches the desired set point (SP) the error reduces proportionally, and so reduces the control output. This results in a steady-state error or gap between the set point and the controlled value (CV) at the output.This steady-state error can be reduced by increasing controller gain, but this turn can lead to the system instability and oscillation.

To overcome these problems it is common to use proportional action combination with derivative and integral action.

Derivative action provides an output signal proportional to the rate of change of the error. Thus, if the rapidly increasing error occurs, then a large correcting output will be produced. As the rate of error change slows, so the derivative output decreases. This improves the system response to dynamic errors but does not improve steady-state error.

Integral action generates an output signal proportional to the mathematical integral of the error, meaning the summed history of the error. This is used to overcome steady-state error, since the integral term provides a matching error output value ; i.e. the output of the integrator will varys as long as the error input is nonzero. When the measured error reaches zero (steady-state error now occuring- achieved by proportional action alone) then the integral output will equal the steady-state error, offsetting it and driving the system into alignment.

1.3 Programmable Logic Control (PLC)

As already known, a programmable logic controller (PLC), or programmable controller is a digital computer used for automation in industrial processes, such as control of machinery on factory assembly lines. Unlike general-purpose computers, the PLC was designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory. A PLC is an example of a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result. In order to function, PLC has to synchronize with CX-Programmer software that allowing users to control PLC from computers. For this project, OMRON CJ1M model of PLC will be used due to the wide range of function and applications.

1.3.1 CX Programmer

The PLC packaged software, CX-Programmer is the programming software for all Omron's PLC series, is fully integrated into the CX-One software suite. CX-Programmer includes a wide variety of features to speed up the development of the PLC program. New parameter-setting dialogues reduce setup time, and with standard function blocks in IEC 61131-3 structured text or conventional ladder language, CX-Programmer makes development of PLC programs a simple drag & drop configuration.

CX-Programmer now includes support for Sequential function charts (SFC)

1. Enables the flow of the program to be understood at a glance
2. Helps to achieve a structured program
3. Easy monitoring and debugging
4. Requires v4 CPU[12]

1.4 Introduction to Coupled-Tank Control Apparatus CT-100

Figure 1.3: Coupled-Tank Control Apparatus CT-100

For this project, we used the CT-100 model of coupled tank system (Figure 1.3). The equipment consists of two small tower-type tanks mounted above a reservoir which functions as storage for the water as in Figure 1.4. Water is pumped into the top of each tank by two independent pumps. The head of water in each tank is clearly visible on the attached scale at the front of the tanks. Each tank is fitted with an outlet, at the side near the base. The amount of water which returns to the reservoir is approximately proportional to the head of water in the tank since the return tube is made of flexible tubing which aids in varying the hydraulic resistance (by the use of a screw-type clamp).

The level of water in each tank is monitored by a capacitive-type probe or transmitter. Signal conditioning circuits (at the rear of the unit) convert the measured capacitance (a function of water level) to electrical signals in the range of 0 to +5 volt DC that will be used for data signal in the project. The zero level has been calibrated to represent the rest point of the water level, that is, when the tank is nearly empty (approximately 20mm on the scale), while the full state (+ 5 volts) is calibrated at the level of the opening to the rear overflow stand pipes with scale showing 300 mm approximately. The calibrated value for the couple tank parameters are shows in table 1.1 below:

Table 1.1 : Data collected from calibration process on couple tank

WATER LEVEL (mm)	**VOLTAGE (Volt)**	
	(measured)	**(calculated)**
300	**5.20**	**5.00**
250	**4.40**	**4.17**
200	**3.60**	**3.33**
150	**2.70**	**2.50**
100	**1.70**	**1.67**
50	**0.90**	**0.83**
0	**0.00**	**0.00**

An internal baffle controls leakage between the two tanks to simulate interacting tank arrangements. The baffle is raised by a small amount by turning the wing-nut on the top of the tank assembly in order to provide a useful range of inter-tank resistance. A spring returns the baffle to the closed position when the wing-nut is released.

The two pumps at the rear of the unit are controlled by PWM (pulse-width modulation) circuits using power MOSFET devices. The input signal to each pump circuit may be a PWM waveform generated by a microcontroller or other external devices or an external DC voltage in the range 0 to +5 volts.

1.4.1 Fundamental Control Principle of Coupled-Tank System

Brief information on the hardware of the system had been discussed previously. Now, a focus on the control principle of Coupled-Tank is brought forward. The basic control principle of the coupled-tank system is to maintain the level of liquid in the tank at a desired set point value when there is inflow of water into tank and outflow of water out of the tank.

The terms that are normally used in process control industries will be used to describe the variable involve in this coupled-tank system. Process variable or controlled variable for this system; that is the variable which quantifies performance; is actually the water level in the coupled-tank control system. To maintain and control the water level at a specified desired value, the inlet flow rate is adjusted. The adjustment is made or actuated by pump voltage. The input flow rate is known as manipulated variable, i.e. the variable that is used to maintain the process variable at its set point.

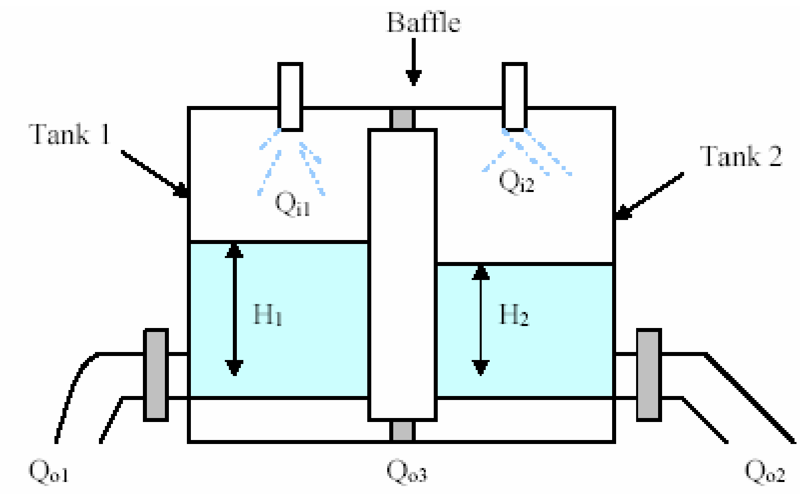

Figure 1.4: Schematic diagram of CTS-100

Figure 1.4 shows the schematic diagram of the coupled-tank system showing the important characteristic of the system. The level will be maintained as long the inflow rate, i.e. the pump flow rate and the outflow rate remained unchanged. However, if any disturbances occur which result in the change in either the inflow rate or the outflow rate, or the changes that may be necessary for the process, then the liquid level in the tank would change and settle at different steady-state level.

If the outflow rate is greater than the inflow rate, the liquid level will settle at a lower level than before, assuming that a steady state condition had already been achieved before the tank is empty. Similarly, if the inflow rate is higher than the liquid level will settle at a higher level assuming that a steady state conditions is achieved before the tank overflows.

The control objective is that the input flow rate has to be adjusted in order to maintain the level at the previous condition. In the case where the outflow rate is greater than the inflow rate, the inflow rate has to be adjusted so that the liquid level in the tank is increased and settled. Table 1.2 below summarizes the condition for the system to be in a steady-state manner.

Table 1.2: Steady-state condition for the coupled-tank system

System Type		**Condition**	**Alternative Condition**
First Order	Tank 1 Tank 2	Water into the tank via the respective inlet equals to water out of tank via the respective outlet	Inflow rate at the inlet equals to outflow rate at the outlet
Second Order	Tank 1	Water into the tank via the respective inlet equals to water out of tank via the respective outlet and the baffle gap.	Inflow rate at the inlet equals to the outflow rate at the outlet plus the outflow rate at the baffle gap.
	Tank 2	Water into the tank via the respective inlet and the baffle gap equals to water out of tank via the respective outlet.	Inflow rate at the inlet plus the inflow rate at the baffle gap equals to the outflow rate at the outlet.

1.4.2 Important parameters of the coupled-tank system

Table 1.3 below shows the default value of the coupled-tank system's parameters.

Table 1.3: Parameters of Coupled-Tank system.

Name	**Expression**	**Value**		
Cross Sectional Area of the coupled tank reservoir	A1&A2	32 cm^2		
Proportionality α constant that depends on discharge coefficient, orifice cross sectional area and gravitational constant	α_i subscript i denotes which tank it refers	α_1	α_2	α_3
		14.30 $cm^{3/2}$ / sec	14.30 $cm^{3/2}$ / sec	20.00 $cm^{3/2}$ / sec
Sensor gain	K_{sensor}	0.157 *V/cm* (0.179 *V/cm* for 2nd tank's sensor)		
Pump gain	K_{pump}	13.571 $cm^3 / s / volt$		
Maximum allowable volumetric flowrate pumped by motor	Qi_{max}	300 cm^3 / s		
Pump motor(valve) time constant	TC	1 sec (can be adjusted)		