Faculty of Electrical Engineering

ANALYSIS OF CONTINUOUS AND DISCRETE CONTROL SYSTEMS USING PID CONTROLLER

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DECLARATION

I declare that this dissertation entitled “Analysis of Continuous and Discrete Control Systems Using PID Controller” is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :…..……..……………………..

Name: : Ashwaq Abdulameer Khalaf

Date: :.....………………………… ....

APPROVAL

I hereby declare that I have read this dissertation and in my opinion, this dissertation is sufficient in terms of scope and quality for the award of Master of Electrical Engineering (Industrial Power).

Signature :…………:……………. ....

Supervisor Name : Prof.Dr. Marizan Bin Sulaiman

Date: :……………………………….. ....

DEDICATION

This dissertation work is dedicated to my country (Iraq), my beloved mother and father, my great husband, my good friends, and my big family; you are good examples have taught me to work hard for the things that I aspire to achieve.

ABSTRACT

The Proportional-Integral-Derivative (PID) control strategy should be understood as a huge part in the engineering education oriented on process control. At the same time, this education could be difficult because of control system transfer function nature; some of this function has a long decimal numbers which make the mathematical calculation and system response analysis difficult. Applying suitable software using Graphical User Interface (GUI) windows able to contribute to enhance the quality of education and give a better understanding of the PID control. This work explains the PID controller three-term parameters affecting the closed-loop control system response. Ziegler-Nichols and manual tuning methods are used for setting the PID controller parameters in *s*-domain. The discrete-time PID controller is the most popular controller because of the technology development in the last few decades. The PID controller parameters are set in *s*-domain before they are converted into *z*-domain using one of the conversion methods. The conversion of the control system with PID controller is quite difficult. This dissertation discusses some of the common conversion methods that are used to convert the PID controller transfer function from continuous-time to the discrete-time and then analyzing the system response behavior in *z*-domain. The analysis of the control system in z-domain is more difficult compared to the s-domain. By using the GUI/MATLAB windows it improves education quality and gives more understanding of both the continuous-time and the discrete-time systems with the PID controller. A typical test on three case studies composing the third-order plant, speed control and position control of DC motor are used to show the implementation of these conversion methods and quality of the resulting z-domain systems. The simulation results from the GUI/MATLAB windows show the effect of sampling time on each one of the selected conversion methods.

ABSTRAK

Berkadar-integral-derivatif (PID) strategi kawalan perlu difahami sebagai sebahagian besar dalam bidang pendidikan kejuruteraan berorientasikan kepada kawalan proses. Dengan menggunakan perisian yang sesuai (Tetingkap GUI) dapat menyumbang kepada peningkatan kualiti pendidikan dan memberi pemahaman yang lebih baik kawalan PID. Tugasan ini menerangkan kesan tiga penggal parameter pengawal PID ke atas sistem kawalan gelung tertutup. Pengawal dalam kaedah penalaan s-domain Ziegler-Nichols dan kaedah penalaan manual digunakan untuk menetapkan parameter PID. PID pengawal diskret masa adalah pengawal yang paling popular kerana pembangunan teknologi dalam beberapa dekad yang lalu. Umumnya, parameter pengawal PID ditetapkan dalam domain-s maka ianya kemudian ditukar menjadi z-domain menggunakan salah satu daripada kaedah penukaran. Disertasi ini membincangkan beberapa kaedah penukaran yang biasa digunakan untuk menukar fungsi pemindahan pengawal PID dari masa- berterusan ke masa diskret dan menganalisis spesifikasi sambutan sistem dalam z-domain. Dengan menggunakan tetingkap GUI / MATLAB ia meningkatkan kualiti pendidikan dan memberi lebih pemahaman Pengawal PID terhadap kedua-dua sistem masa - berterusan dan masa diskret. Ujian khas terhadap tiga kajian kes, untuk mengarang loji ketiga , kawalan kelajuan motor DC dan kawalan kedudukan motor DC digunakan untuk menunjukkan hasilvpelaksanaan kaedah penukaran dan kualiti sistem z-domain. Keputusan simulasi dari tingkap GUI / MATLAB menunjukkan kesan persampelan masa kepada setiap kaedah penukaran yang dipilih. Pakej perisian ini disasarkan untuk melatih pelajar kejuruteraan dan juga kepada generasi baru menjinakkan diri dalam bidang kejuruteraan untuk memahami reka bentuk dan analisis pengawal PID.

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LIST OF ABBREVIATIONS

Abbreviation	**Specification**
PID	Proportional Integral Derivative
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
ZOH	Zero Order Hold
DC	Direct Current
GUI	Graphical User Interface
P	Proportional
I	Integral
D	Derivative
PI	Proportional Integral

LIST OF SYMBOLS

Symbol	Specification
$r(t)$	System input
$e(t)$	Difference between the system input and output
$u(t)$	Control output
$y(t)$	System output
G_c	Controller transfer function
G_p	Plant transfer function
H	Closed loop system feedback
T_r	Rise time
T_p	Peak time
M_p	Maximum overshoot
T_s	Settling time
e_{ss}	Steady-state error
K_p	Proportional gain
K_i	Integral gain
K_d	Derivative gain
R	Resistor
C	Capacitor
T_i	Integral time constant
T_d	Derivative time constant
T	Sampling time
ω_n	System frequency
ω_b	System bandwidth

ω_s	Sampling frequency
T_m	Motor torque
K_T	Torque constant
I_a	Armature current
V_a	Input voltage
R_a	Armature resistance
L_a	Armature inductance
V_b	Back electromotive force (EMF)
K_b	EMF constant
ω	Angular velocity of rotor
K_L	Load torque
J	Rotor inertia
b	Friction constant
T_d	Disturbance torque
θ	Angular position of rotor shaft
K_{cr}	Critical gain
P_{cr}	Corresponding period

LIST OF PUBLICATIONS

1. A. A. Khalaf, Marizan Sulaman, M.S.M. Aras, D. Saleem, "GUI Based Control System Analysis Using PID Controller for Education", Published in TELKOMNIKA Indonesian Journal of Electrical Engineering and Computer Science (TELK-IJEECS). Vol.3, No.1, July 2016.

2. A. A. Khalaf, Marizan Sulaman, M.S.M. Aras, D. Saleem, "Tuning Methods of PID Controller for DC Motor Speed control", Published in TELKOMNIKA Indonesian Journal of Electrical Engineering and Computer Science (TELK-IJEECS). Vol.3, No.2, August 2016.

CHAPTER 1

INTRODUCTION

1.1 Background

The PID controller (Proportional-Integral-Derivative) controller is a three-term controller and one of the earlier control strategies, starting from the beginning of the previous century. PID controllers are everywhere, it remains as the heart component in industrial process control as more than 95% of closed-loop industrial processes in use today are controlled by PID controller or modified PID controller (Astrom, 2002). PID controller structure is simple, that make it relatively easy to understood and tune by plant operators. In industrial, PID controller prefers to use in many application which makes it the standard controller, that because of the simplicity and excellent of this type of controller. PID controller is not expensive and has the ability to fit with a wide range of processes (Aggarwal et al., 2012). PID controller can be successfully applied when the basic controllers unsatisfactory the required performance or when the system needs more intricate control type. Typically it is used to control variables like the temperature in thermal systems, position and velocity in mechanical systems, and voltage, current, or frequency in electrical systems (Astrom and Hagglund, 1995; Visioli, 2006).

The aim of using control system is to drive a process or plant by keeping the output response of the system closes as much as possible to the desired response. That can be done by using a closed-loop control system with negative unity feedback. In this closed-loop system $G_c(t)$ represents the PID control transfer function, $G_p(t)$ represents the plant transfer function, and $H(t)$ represents the feedback transfer function. For unity feedback $H(t) = 0$. The input to the controller represent the result of comparing the process output to the reference input value as shown in Figure 1.1 where *r(t)* is the desired value of the input signal, *e(t)* represent the difference between the desired value and the system output, *u(t)* represent the control variable, and *y(t)* is the system output (Mutambara, 1999; Ghosh, 2007).

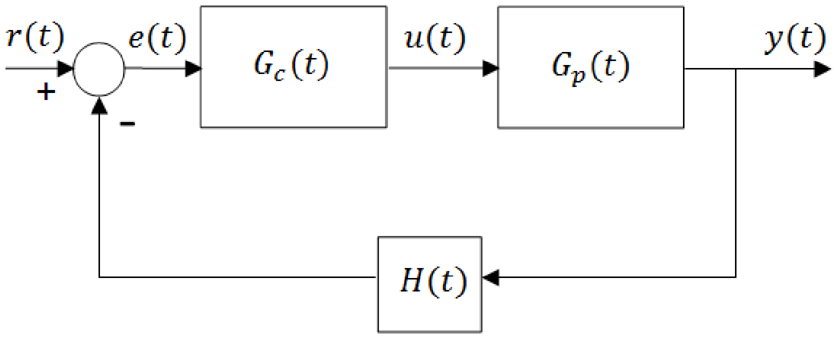

Figure 1.1: Closed-loop control system (time-domain).

PID controller used in the majority of the control systems. PID controller proves to be most useful control, especially when the mathematical model of the plant is missed and analytical design methods cannot be used. PID controller has proved its usefulness in providing satisfactory control to the system response (Visioli, 2006).

Transient response specifications should be known to understand the PID parameters effect on the control system response. The transient performance explains the initial behavior control system before the control system gets it steady state behavior. The control system response usually tested with the unit step input to analyzing its transient response behavior. If the system response to a step input is known that mean it is mathematically possible to compute the response to any other input. The control engineer, in general, gives a great interest on the second-order systems because the higher-order system at the end can be approximated by the second-order system and first-order system (the first-order system decays just with time). Figure 1.2 show second-order system transient response (Ronald S. Burns, 2001; Ogata, 2010):

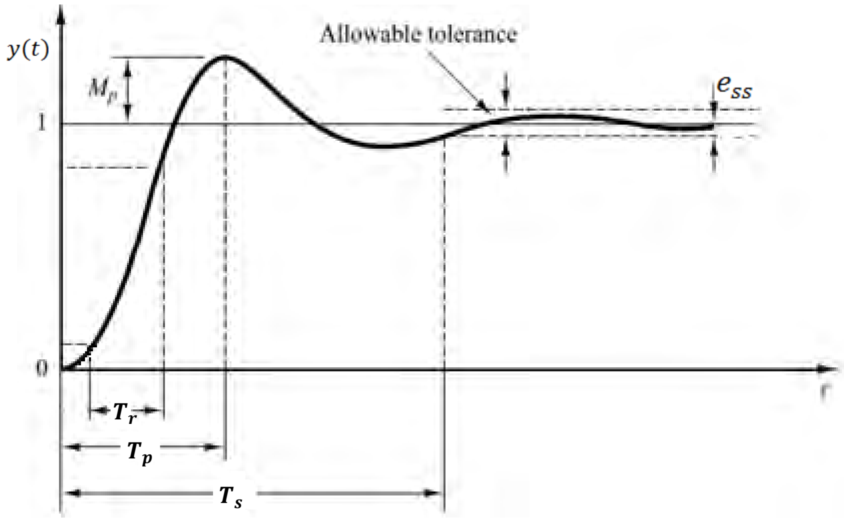

Figure 1.2: Unit step response for the closed-loop system.

1. Rise time T_r: it is the time that the system response take to rise from 10% to 90% of its final desired value.
2. Peak time T_p: it is the time that the system response take to reach the first peak of the overshoot (or to reach the maximum error).
3. Maximum overshoot M_p%: it is the maximum peak value (maximum error) of the system response curve measured from unity (or from the desired value). It is common to use the maximum percent overshoot with the unity step input.
4. Settling time T_s: it is the time that the system response curve take to reach and stay within a range about the final value of size specified by absolute percentage of the final value (usually 2% or 5%). Its largest time constant of the control system.
5. Steady-state error e_{ss}: The steady-state error represents the difference between the steady system output response and the desired response.