IMPROVED GRAVITATIONAL SEARCH ALGORITHM FOR PROPORTIONAL INTEGRAL DERIVATIVE CONTROLLER TUNING IN PROCESS CONTROL SYSTEM

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Specially dedicated to Aziz B. Lebai Hashim and Azizah Bt. Ali,

my only sister Ummu Syahidah Bt. Aziz,

Thank you for everything.

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ABSTRACT

Proportional-Integral-Derivative (PID) controller is one of the most used controllers in the industry due to the reliability and simplicity of its structure. However, despite its simple structure controller, the tuning process of PID controller for nonlinear, high-order and complex plant is difficult and faces lots of challenges. Conventional method such as Ziegler-Nichols are still being used for PID tuning process despite its lack of tuning accuracy. Nowadays researchers around the world shift their attention from conventional method to optimisation-based methods. For the last five years, optimisation techniques become one of the most popular methods used for tuning process of PID controller. Optimisation techniques such as Genetic Algorithm (GA), Particle Swarm Optimisation (PSO) as well as Gravitational Search Algorithm (GSA) are widely used for the PID controller application. Despite the effectiveness of GSA for PID controller tuning process compared to the GA and PSO technique, there is still a room for improvement of GSA performance for PID controller tuning process. This research represents the additional characters in GSA to enhance the PID controller parameter tuning performance which are Linear Weight Summation (LWS) and alpha parameter range tuning. Performance of optimisation-based PID controllers are measured based on the transient response performance specification (i.e. rise time, settling time, and percentage overshoot). By implementing these two approaches, results show that Improved Gravitational Search Algorithm (IGSA) based PID controller produced 20% to 30% faster rise and settling time and 25% to 35% smaller percentage overshoot compared to GA-PID and PSO-PID. For real implementation analysis, IGSA based PID controller also produced faster settling time and lower percentage overshoot than other optimisation-based PID controller. A good controller viewed as a controller that produced a stable dynamic system. Therefore, by producing a good transient response, IGSA based PID controller is able to provide a stable dynamic system performance compared to other controllers.

ABSTRAK

Pengawal Perkadaran-Kamiran-Pembezaan (PID) adalah salah satu pengawal yang paling banyak digunakan di dalam industri kerana kebolehpercayaan dan strukturnya yang ringkas. Walaupun mempunyai struktur pengawal yang ringkas, proses penalaan pengawal PID untuk sistem tertib tinggi, tak lelurus dan kompleks adalah sukar dan menghadapi banyak cabaran. Kaedah konvensional seperti Ziegler-Nichols masih digunakan untuk proses penalaan PID meskipun mempunyai ketepatan penalaan yang rendah. Kini, penyelidik di seluruh dunia mengalih perhatian mereka dari kaedah konvensional kepada kaedah berasaskan pengoptimuman. Sejak lima tahun yang lalu, teknik pengoptimuman menjadi salah satu kaedah yang paling popular yang digunakan untuk proses penalaan pengawal PID. Teknik pengoptimunan seperti Algoritma Genetik (GA), Pengoptimunan Zarah Kerumunan (PSO) dan juga Algoritma Pencarian Graviti (GSA) digunakan secara meluas didalam penggunaan pengawal PID. Walaupun GSA berkesan didalam proses penalaan pengawal PID berbanding teknik GA dan PSO, masih ada ruang untuk penambahbaikan prestasi GSA untuk proses penalaan pengawal PID. Penyelidikan ini memperincikan ciri-ciri tambahan dalam GSA untuk meningkatkan prestasi proses penalaan pengawal PID iaitu Penjumlahan Berat Linear (LWS) dan penalaan parameter alfa yang pelbagai. Prestasi pengawal PID berasaskan pengoptimunan diukur berdasarkan prestasi sambutan fana (masa naik, masa menetap, dan peratusan terlajak). Dengan melaksanakan kedua-dua pendekatan, keputusan menunjukkan bahawa pengawal PID berasaskan GSA Terpilih (IGSA) menghasilkan 20% hingga 30% lebih cepat untuk masa meningkat dan masa penetapan dan 25% hingga 35% lebih kecil untuk peratusan terlajak berbanding GA-PID dan PSO-PID. Untuk analisis pelaksanaan masa sebenar, pengawal PID berasakan IGSA juga menghasilkan masa penetapan yang lebih cepat dan peratusan terlajak yang lebih rendah daripada pengawal PID berasaskan pengoptimuman yang lain. Pengawal yang baik boleh ditafsirkan sebagai pengawal yang menghasilkan satu sistem dinamik yang stabil. Oleh itu, dengan menghasilkan sambutan fana yang baik, pengawal berasas IGSA PID mampu memberikan prestasi sistem dinamik yang stabil berbanding dengan pengawal lain.

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LIST OF ABBREVIATION

WWTP	-	Wastewater treatment plant
ASP	-	Activated sludge process
HV	-	Heat and Ventilation
PID	-	Proportional-integral-derivative
SISO	-	Single input single output
MIMO	-	Multiple input multiple output
GA	-	Genetic Algorithm
PSO	-	Particle swarm optimisation
GSA	-	Gravitational search algorithm
IGSA		Improved gravitational search algorithm
RTWT	-	Real time window target
DAQ	-	Data acquisition
TRIAC	-	Trinode of alternate current
RTD	-	Resistive temperature detector
PC	-	Personal computer
NI	-	National instrument
HV	-	Heating and ventilation
MRAC	-	Model reference adaptive control
MPC	-	Model predictive control
SA	-	Simulated annealing
AGSA	-	Adaptive gravitational search algorithm
DE	-	Differential evolution
EA	-	Evoluntionaty algorithm
ACO	-	Ant colony optimisation

FA	-	Firefly algorithm
CS	-	Cuckoo search
VEGSA	-	Vector evaluated gravitational search algorithm
ESS	-	Steady state error
NP	-	Number of population
LWS	-	Linear weight summation
SITO	-	Single input two output

LIST OF SYMBOLS

$X(t)$	-	Biomass concentration
$S(t)$	-	Substrate concentration
$X_r(t)$	-	Recycled biomass concentration
$C(t)$	-	Dissolved oxygen concentration
D	-	Dilution rate
W	-	Air flow rate
K_S	-	Affinity constant
K_C	-	Saturation constant
μ_{max}	-	Maximum growth rate
K_P	-	Proportional gain
K_I	-	Integral gain
K_D	-	Derivative gain
P_c	-	Crossover rate
P_m	-	Mutation rate
p_{best}	-	Best particle
g_{best}	-	Global best
Ω	-	Inertia weight
$G(t)$	-	Gravitational constant
$G(t_0)$	-	Initial value of gravitational constant
A	-	Alpha

Iter	-	Current iteration
$iter_{max}$	-	Maximum iteration
σ_j	-	Random generated number
r_{e1}	-	Ratio of exploration
r_{e2}	-	Ratio of explanation

CHAPTER 1

INTRODUCTION

1.1 Introduction

Control engineering foundation consists of feedback theory and linear system analysis, where control engineering is not limited to electrical engineering discipline only but applicable to other field such as chemical, mechanical, aeronautical, and civil engineering. The main idea of control engineering is to improve, or enable the system performance by adding sensors, control processor and actuator (Boyd and Barratt, 1991).

In (Boyd and Barratt, 1991), control system is defined as an interconnected components that forms a system configuration that will provide a desired system response. Basic control system includes sensors, control processors and actuator. The schematic diagram of a general control system is shown in Figure 1.1.

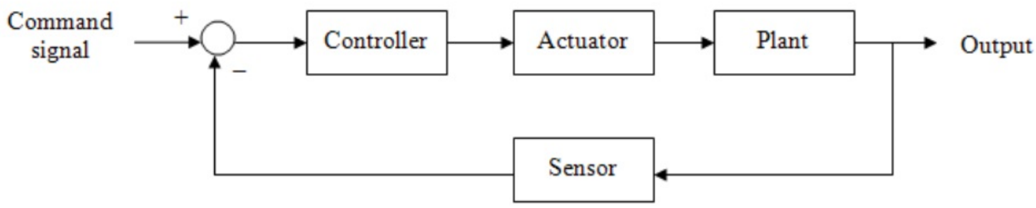

Figure 1.1: Schematic diagram of a general control system (Boyd and Barratt, 1991)

In Figure 1.1, the function of a sensor is to sense and measure various signals in the system, a controller processes the sensed signal and drives the actuator, which affect the behavior of the plant. Since the sensor signal may affect the system which is to be controlled, the control system shown in Figure 1.1 above is called a feedback or closed-loop control system. The feedback term is refered to the signal loop that circulated clockwise in the figure above. In contrast, a control system without sensors which generates the actuator signal from the command signals alone is called an open-loop system.

In control design process, the most critical element is the process of adjusting the controller parameter where this process is widely known as controller tuning process. This process must be done to ensure the controller to provide the desired performance of the system. There are lots of controllers available in the market from the simple controllers such as Proportional-Integral-Derivative (PID) and optimal controllers likes Linear-Quadratic Regulator (LQR) and Linear Quadratic Gaussian (LQG). The complexity of a controller is based on the controller parameters that need to be tuned, where the more controller parameters needed to be tuned, the more complex is the controller. In this research, the priority is to find the optimal approach for optimising the performance of PID controller.

Despite the popularity of the controller employed with its simple structure, the tuning process difficulty of the PID controller mainly depends on the behavior of the plant itself (Astrom et al., 1993). The elements that contribute to the difficulties in tuning process are the nonlinearity of the system itself, unstable open-loop system, under-actuation and the order of the system (Atherton and Zhuang, 1992). Thus, this research tries to propose an algorithm that automatically give the user the optimised PID controller parameters for the objectives likes settling time, percentage overshoot and steady-state error in the system.

1.2 Problem Statement

Despite the popularity of PID controller as the most practical controller in control engineering, there were still drawbacks reported. Around 30 % of the installed PID controllers in industrial are still operating in manual mode and around 65 % of automatic PID controllers are poorly tuned (Rani, 2012). On the other hand, a study from Van Overschee in 1997 shows that more than 75 % of total PID controllers installed are badly tuned and over than 20 % of the total PID controllers are set under default setting, which means that the controllers are not tuned at all. These situations shows that the tuning process of PID controllers are the most critical criteria in tuning operators in which the existing tuning methods are not well compatible for the tuning problems in industry.

Hence this research tries to produce an alternative approach of tuning the PID controllers. It is believed that the developed algorithm in this research will provide the users or designers with the automatic optimized PID controller with less complex tuning process.

1.3 Research Objectives

The aim of this research is to develop a new variance of optimization algorithm for the tuning process of PID controller. The objectives are:

1) To study the process system flow in Activated Sludge Process (ASP) and VVS-400 heat and ventilation system
2) To apply Gravitational Search Algorithm (GSA) optimisation techniques as main tuning mechanism of PID controller
3) To analyze the closed loop performance of both systems using GSA-PID and other optimisation algorithms such as Genetic Algorithm (GA) and Particle Swarm Optimisation (PSO) via simulation analysis

4) Develop a variance of GSA that can enhancing the performance of PID controller for simulation and hardware analysis of both ASP and VVS-400 process system

1.4 Research Scopes

This research consists of a few focus works in order to achieve its objectives.

1) Developing an enhancement optimisation algorithm to optimally tune the PID controller performances like settling time, steady state error and percentage overshoot.
2) Analysing the performance of enhancement optimisation algorithm involved based on the output transient responses produced and comparing to well-known algorithms.
3) Applying all the optimisation-based PID controllers to the VVS-400 pilot for controller's validation process in real time implementation.

1.5 Research Contribution

The main contributions from this research is introduction of a variants of GSA called Improved Gravitational Search Algorithm that able to enhance the PID controller performances by producing better transient responses than other optimisation-based PID controller which are GSA-PID, PSO-PID and GA-PID.

1.6 Thesis Structure

This thesis basically divided into five chapters. Chapter 2 presents the review on previous works that was conducted on Wastewater Treatment Plant (WWTP) especially in Activated Sludge Process (ASP) plant and heat ventilation system especially on VVS-400 plant related to the controller implementations. PID controller tuning methods also been covered involving both conventional and alternatives approaches.

Chapter 3 presents the flow and methodology on the development of Improved GSA-PID controller. The implementation of GSA and other optimisation methods such as PSO and GA which define the tuning parameters of PID controller are also will be explained in this chapter..

Chapter 4 provides the results of the transient performances by using Improved GSA-PID controller and other optimisation-based PID controller such as GA-PID and PSO-PID. The thorough analysis on all optimisation-based PID controllers will be discussed in this chapter. This chapter also shows the transient performance of all optimisation-based PID controllers in real time application system. All the works involved in this chapter were done in simulation system of ASP and VVS-400 as well real plant of VVS-400 using MATLAB Simulink platform.

Chapter 5 consists of conclusion based on the overall results and analysis that was done. The improvement and future works relates to this project are also included in this chapter.

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