MULTI-OBJECTIVE OPTIMIZATION OF PID CONTROLLER PARAMETERS USING GENETIC ALGORITHM

MOHD RAHAIRI BIN RANI

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Universiti Teknologi Malaysia

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To my late father

To my beloved family

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

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ABSTRACT

Proportional-Integral-Derivative (PID) controller is one of the most popular controllers applied in industries. However, despite the simplicity in its structure, the PID parameter tuning for high-order, unstable and complex plants is difficult. When dealing with such plants, empirical tuning methods become ineffective while analytical approaches require tedious mathematical works. As a result, the control community shifts its attention to stochastic optimisation techniques that require less interaction from the controller designers. Although these approaches manage to optimise the PID parameters, the combination of multiple objectives in one single objective function is not straightforward. This work presents the development of a multi-objective genetic algorithm to optimise the PID controller parameters for a complex and unstable system. A new genetic algorithm, called the Global Criterion Genetic Algorithm (GCGA) has been proposed in this work and is compared with the state-of-the-art Non-dominated Sorting Genetic Algorithm (NSGA-II) in several standard test problems. The results show the GCGA has convergence property with an average of 35.57% in all problems better than NSGA-II. The proposed algorithm has been applied and implemented on a rotary inverted pendulum, which is a nonlinear and under-actuated plant, suitable for representing a complex and unstable high-order system, to test its effectiveness. The set of pareto solutions for PID parameters generated by the GCGA has good control performances (settling time, overshoot and integrated time absolute errors) with closed-loop stable property.

ABSTRAK

Pengawal Perkadaran-Kamiran-Pembezaan (PID) adalah salah satu daripada pengawal-pengawal yang banyak digunakan di industri. Walau bagaimanapun, selain memiliki struktur yang ringkas, penalaan parameter-parameter PID untuk sistem yang tidak stabil, kompleks dan bertertib tinggi menjadi sukar untuk disempurnakan. Apabila berhadapan dengan sistem sedemikian, kaedah-kaedah empirikal menjadi tidak berkesan dan kaedah-kaedah analitik memerlukan jalan kerja matematik yang rumit. Kesannya, komuniti kawalan cuba mengalihkan perhatian kepada kaedah-kaedah stokastik yang kurang memerlukan interaksi daripada jurutera. Walaupun kaedah-kaedah ini berjaya menalakan parameter-parameter PID, penggabungan pelbagai objektif dalam satu fungsi objektif masih tidak begitu jelas. Tesis ini memperincikan pembangunan satu algoritma evolusi pelbagai objektif untuk mengoptimumkan parameter-parameter PID bagi satu sistem yang kompleks dan tidak stabil. Algoritma yang dicadangkan iaitu Algoritma Genetik Berkreteria Global (GCGA) akan dibandingkan dengan algoritma yang popular, Algoritma Genetik Penyusunan Tak-didominasi (NSGA-II) dalam beberapa permasalahan. Keputusan menunjukkan GCGA mempunyai purata 35.57% kadar penumpuan yang lebih baik berbanding NSGA-II dalam semua pengujian. Algoritma cadangan telah diaplikasikan ke atas bandul songsang berputar yang merupakan satu sistem tidak linear yang sesuai untuk mewakili sistem yang kompleks, bertertib tinggi dan tidak stabil. Set penyelesaian-penyelesaian pareto yang diperolehi melalui GCGA mempunyai sifat-sifat kawalan (masa pengenapan, kelajakan dan ralat masa mutlak bersepadu) yang baik dengan mematuhi sifat kestabilan sistem tertutup.

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LIST OF ABBREVIATIONS

c_1	-	Distance to arm centre of mass
c_2	-	Distance to pendulum centre of mass
DTLZ	-	Deb-Thiele-Laumans-Zitzler
EA	-	Evolutionary Algorithm
ES	-	Evolution Strategy
GA	-	Genetic Algorithm
GCGA	-	Global Criterion Genetic Algorithm
GP	-	Genetic Programming
HLGA	-	Hajela and Lin Genetic Algorithm
J_1	-	Inertia of arm
J_2	-	Inertia of pendulum
K_b	-	Back EMF constant
K_d	-	PID derivative gain
K_i	-	PID integral gain
K_p	-	PID proportional gain
K_t	-	Torque Constant
l_1	-	Length of the arm
l_2	-	Length of the pendulum
LQR	-	Linear Quadratic Regulator
M	-	No. of objectives
m_1	-	Mass of the arm
m_2	-	Mass of the pendulum
MOEA	-	Multi-objective Evolutionary Algorithm
N	-	No. of individual in population
NSGA	-	Non-dominated Sorting Genetic Algorithm
NSGA-II	-	Elitism Non-dominated Sorting Genetic Algorithm
p_c	-	Crossover probability
PID	-	Proportional-Integration-Derivative

p_m	-	Mutation probability
PSO	-	Particle Swarm Optimization
RIP	-	Rotational Inverted Pendulum
R_m	-	Armature resistance
SPEA	-	Strength Pareto Evolutionary Algorithm
ZDT	-	Zitzler-Deb-Thiele

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Controller design is an essential aspect in control engineering in order to ensure a controlled plant to perform well. The controller or control law describes the algorithm or the signal processing employed by the control processor to generate the actuator signal from the sensors and command signals it receives (Chen, 1992). Figure 1.1 shows the configuration of the controller, actuator, plant and sensor in a feedback or closed-loop system. The controller receives command signal and after that compares it with the present output measured by the sensor. The controller then send the appropriate signal to the actuator in order to ensure the plant produces the same output as the command signal.

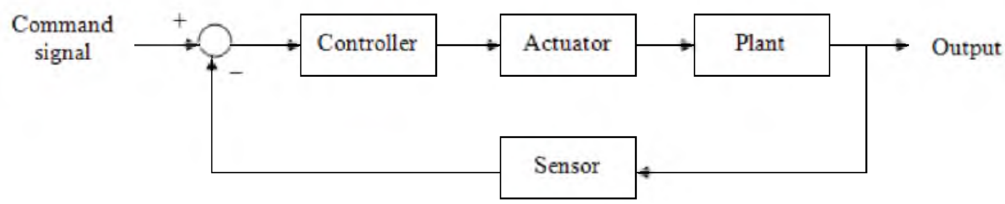

Figure 1.1: Block diagram of the controller, actuator, plant and sensor in a feedback or closed-loop system

The signal value send by the controller completely depends on the parameters in the controller. The adjustment of the controller parameters or sometimes called controller tuning is a critical element in the controller design process. Simple controllers like Proportional-Integral-Derivative (PID) controller only requires few parameters to be tuned but complicated controllers like Linear-Quadratic Regulator (LQR) and Linear Quadratic Gaussian (LQG) have more parameters to deal because they considered more states in the designs (Bemporad et al., 2002). These complicated controllers however are developed in such way so it will produce optimum control signal (Polyak and Tempo, 2001). The controller design only has to decide on the value of the weights associated with the various signals in the system. On the other hand, this research aims to find an approach to optimize the performances of the PID controllers.

Despite the simplicity in its structure and being the most popular type of controller employed, the level of difficulty in the PID controller tuning mainly depends on the plant behaviours (Åström and Hägglund, 2001). Nonlinearity, instable open-loop system, under-actuation and the system's order are the elements that contribute to the difficulties of tuning process (Zhuang and Atherton, 1993). Therefore this research used a rotational inverted pendulum (RIP) to demonstrate the difficulties in tuning the PID control parameters for a very nonlinear and under-actuated system. The under-actuated (two degree of freedoms, one actuator) property of RIP also demonstrates the tuning example of two PID controllers simultaneously. This condition will add to the difficulties in PID tuning.

Referring to the above conditions, the existing PID tuning methods are not capable to tune the combination of PID parameters when facing such plants. Thus this research tries to propose an algorithm that automatically gives the user the optimized PID parameters for the objectives like steady-state error, settling time and overshoot in the system.

1.2 Importance of the Works

Despite the popularity of PID controllers as the most practical controller for control engineer, Ender (1993) reports that 30% of the installed PID controllers are operating in manual mode and 65% of the automatic controllers are poorly tuned. Moreover, a study from Van Overschee et al. (1997) shows 80% of PID controllers are badly tuned and 25% of the PID controllers are operating under default factory settings, means the controllers are not tuned at all. Recently, O'Dwyer (2009) states the proposed tuning methods in literature are not having significant impact in the industrial practises. These situations implies the tuning PID controllers are the vexing problems to the tuning operators which maybe the tuning rules available are not well compatible for their tuning problems in industry.

Hence this research tries to provide an alternative approach for tuning PID controllers. The developed algorithm in this research will automatically provide the designers with the optimized PID parameters with less rules of tuning.

1.3 Research Objectives

The main objectives of this research are

i. To develop a multi-objective optimization algorithm based on evolutionary techniques for tuning PID controller parameters.
ii. To compare the proposed algorithm with the well known multi-objective GA.
iii. To apply the optimized PID controller to an under-actuated plant, rotational inverted pendulum (RIP) in the simulation and real plant.

1.4 Scope of Work

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

i. Developing a multi-objective optimization algorithm to optimally tune the PID controller performances like settling time, steady state errors and overshoot using multi-objective genetic algorithms (MOGAs) approach.

ii. Analysing the optimization algorithm using several test problems borrowed from literature and comparing to a well-known algorithm.

iii. Applying the results of optimized PID controller simulation to the real plant in order to validate the algorithm in the real implementation.

1.5 Research Contribution

The main contributions of this research are

i. Introduction of a variant of MOGAs called Global Criterion Genetic Algorithm (GCGA).

ii. Optimization of PID controller tuning using GCGA.

iii. Simulation and experimental validation of optimized PID controller tuning.

1.6 Thesis Outline

This thesis consists of six chapters. Chapter 2 provides a discussion of the fundamentals of PID controller and a number of popular tuning methods for PID controller. Both conventional and alternative approaches are covered in this chapter.

Chapter 3 discusses the literature review for evolutionary algorithm (EA), the application of EA in the controller tuning problem and the multi-objective genetic algorithms (MOGAs). Previous work done by the researchers in the area of MOGAs will be used as the basis for the proposed algorithm in Chapter 4.

Chapter 4 presents the detailed methodology of the proposed algorithm called Global Criterion Genetic Algorithm (GCGA). Moreover, the modelling of the rotational inverted pendulum through derivation from the equations of motion is presented.

Chapter 5 analyzes the GCGA through several popular test problems and compares its performances with the well known Non-dominated Sorting Genetic Algorithm II (NSGA-II). This chapter also shows the optimization work of the PID controller using GCGA in the simulation and real RIP.

Chapter 6 concludes the thesis and suggests several further investigations of the optimization work.

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