MULTIVARIABLE PID CONTROL TUNING BASED ON OPTIMIZATION TECHNIQUE FOR WASTEWATER TREATMENT PLANT

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MULTIVARIABLE PID CONTROL TUNING BASED ON OPTIMIZATION TECHNIQUE FOR WASTEWATER TREATMENT PLANT

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ABSTRACT

Control designs of wastewater treatment plants (WWTP) become significant nowadays. This is due to the changes in parameters and influent characteristics. WWTP involve a multivariable process which is highly complex and tuning of the control is not easy. In this work, proportional-integral-derivatives (PID) controllers is used. Through a proper tuning of PID controller will result in better closed loop performance of the system. The PID tuning parameters used in this work have been obtained by optimization technique. Two types of optimization method used; particle swarm optimization (PSO) and genetic algorithm (GA) techniques. The tuning parameters have been obtained and the multivariable PID control has been applied to WWTP. The simulation results show better improvement in closed loop performance.

ABSTRAK

Reka bentuk kawalan loji rawatan air menjadi penting pada masa kini. Ini adalah disebabkan oleh perubahan dalam parameter dan ciri-ciri aliran sungai. Loji rawatan air melibatkan proses pembolehubah yang sangat kompleks dan penalaan kawalan tidak mudah. Dalam kerja ini, *proportional-integral-derivatives* (PID) pengawal digunakan. Melalui penalaan yang betul pengawal PID akan mengakibatkan prestasi gelung tertutup sistem lebih baik. Parameter penalaan PID yang digunakan dalam kerja-kerja ini telah diperolehi oleh teknik pengoptimuman. Dua jenis kaedah pengoptimuman digunakan; *particle swarm optimization* (PSO) dan teknik *genetic algorithm* (GA). Parameter penalaan telah diperolehi dan kawalan PID pembolehubah telah digunakan untuk loji rawatan air Keputusan simulasi menunjukkan peningkatan yang lebih baik dalam prestasi gelung tertutup.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	ACKNOWLEDGEMENT	iii
	ABSTRACT	iv
	ABSTRAK	v
	TABLE OF CONTENTS	vi
	LIST OF TABLES	ix
	LIST OF FIGURES	x
	LIST OF APPENDICES	xii
1	**INTRODUCTION**	1
	1.1 Background of Study	1
	1.2 Problem Statement	2
	1.3 Objectives	2
	1.4 Project Scopes	3
	1.5 Project Outline	3
2	**LITERATURE REVIEW**	5
	2.1 Introduction	5
	2.2 Multivariable PID	5
	2.3. Multivariable PID Tuning Method	8

	2.4. Optimization Technique	10
	2.5. Genetic Algorithm and Particle Swarm Optimization	13
	2.6. Performance index	14
3	**METHODOLOGY**	17
	3.1 Introduction	17
	3.2 Flow of the study	17
	3.3 Wastewater Treatment Plant	20
	3.4 Multivariable PID Tuning	24
	3.4.1 Davison method	25
	3.4.2 Penttinen-Koivo method	25
	3.4.3 Maciejowski method	26
	3.4.4 Proposed Combined method	27
	3.5 Optimization Technique	27
	3.5.1 Particle Swarm Optimization	28
	3.5.2 Genetic Algorithm	31
	3.6 Objective Function	37
	3.7 Simulation	38
4	**RESULT AND DISCUSSIONS**	40
	4.1. Introduction	40
	4.2. Open Loop Response	41
	4.3. PSO and GA Search	43
	4.4. Comparison between PSO and GA using Davison	44
	4.5. Results of MPID tuning using PSO	46
	4.6. Results of MPID tuning using GA	50
	4.7 Results of best MPID tuning using PSO and best MPID using GA	54
5	**CONCLUSION AND FUTURE WORKS**	57

5.1 Introduction 57
5.2 Conclusion 57
5.3 Future Works 59

REFERENCES 60
Appendices 65

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	Initial condition value	22
3.2	Kinetic parameter value	22
3.3	Parameter initialization in PSO algorithm	31
3.4	GA initialization	35
4.1	Open loop system performance data	42
4.2	MPID tuning parameter data using PSO	49
4.3	MPID tuning parameter data using GA	54
4.4	Best MPID tuning data	55

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Multivariable system	7
2.2	The PID tuning method classification	10
2.3	Optimization tools and techniques	11
2.4	Meta-heuristic algorithms for optimization	12
3.1	Methodology flowchart	19
3.2	Diagram of PID controller with optimization technique	19
3.3	Activated Sludge Process	20
3.4	Multivariable PID control system	25
3.5	PSO flowchart	29
3.6	GA flowchart	33
3.7	Nonlinear model of Simulink	39
4.1	Open loop step response of WWTP	41
4.2	Open loop bode diagram of WWTP	42
4.3	Graph of Fitness function versus iteration (PSO)	43
4.4	Graph of Fitness function versus iteration (GA)	43
4.5	Graph of fitness function versus number of particle/populations	45
4.6	Graph of computational time versus number of particle/population	45
4.7	MPID output 1 response with PSO as parameter tuning (G_{11})	46
4.8	MPID output 2 response with PSO as parameter tuning (G_{22})	47
4.9	MPID system interaction due to input 2 using PSO as parameter tuning (G_{12})	47

4.10	MPID system interaction due to input 2 using PSO as parameter tuning (G_{21})	48
4.11	MPID system responses using PSO as parameter tuning	48
4.12	MPID output 1 responses with GA as parameter tuning (G_{11})	51
4.13	MPID output 2 responses with GA as parameter tuning (G_{22})	51
4.14	MPID system interaction due to input 2 using GA as parameter tuning (G_{12})	52
4.15	MPID system interaction due to input 1 using GA as parameter tuning (G_{21})	52
4.16	MPID system response using GA as parameter tuning	53
4.17	Output response 1 using Proposed-Combined method	55
4.18	Output response 2 using Proposed-Combined method	56

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Particle Swarm Optimization (PSO) MATLAB coding	65
B	Genetic Algorithm (GA) MATLAB coding	69
C1	Davison method performance index MATLAB coding	76
C2	Penttinen-Koivo method performance index MATLAB coding	77
C3	Maciejowski method performance index MATLAB coding	79
C4	Proposed Combined method performance index MATLAB coding	81
D	Wastewater Treatment Plant MATLAB coding	83
E	MPID tuning parameter data	88
F	MPID controller Simulink block diagram	96
G	Gantt chart	98

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Wastewater treatment plant (WWTP) is a process of treating the water by removing the organic waste and nutrients. It can be categorized into several stages which are primary, secondary, and tertiary treatment. Activated sludge process is one of the process that fall off under secondary treatment. It is a biological process which responsible in maintaining the pollutant substrate and dissolve oxygen within acceptable range. The process involves a number of interacting controls. After commisioning of the plant, the controller parameter are left unchanged. Hence. due to the environment conditions (e.g. rain and flood) poor plant performance observed. Effective and proper tuning of multivariable PID tuning will improves the performances of WWTP. Optimization technique will be used in this study to obtain the parameter tuning.

1.2 Problem Statement

Nowadays, most of the industrial processes are multivariable system. Due to complexity of the system, controlling multivariable system are more than Single-input Single-output system (SISO). PID control is one of the controller that can be apply for both multivariable and SISO system. Eventhought PID control can be consider as a conventional controller, it simplicity make it more favourable controller in industry. Either in SISO or multivariable obtaining a proper parameter tuning is crucial. Manual trial and error method still being used in determining the parameter tuning in PID. The method is consider to be tedious, time consuming and not guarantee to give the best performance. Hence, tuning parameters based on optimization technique were proposed in this study.

1.3 Objectives

The aim of this project is to obtain parameter tuning based on optimization technique. Therefore the objectives are:

1) To study the Multivariable PID (MPID) control tuning method
2) To use the optimization technique for MPID control tuning based on Wastewater Treatment Plant
3) To analyze the closed loop performance of system using Particle Swarm Optimization(PSO) and Genetic Algorithm (GA)

1.4 Project Scopes

This project use MPID controller design for wastewater process. Four types of MPID control tuning will be used which are Davison, Penttinen-Koivo, Maciejowski and Proposed Combined method. Scalar parameter of MPID will be tune using optimization technique. Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are the two optimization technique that selected to be used in this study. Only basic PSO and GA algorithm are implement in the system. The result of are based on the performance of non-linear system. All simulation work will done by using MATLAB/SIMULINK software.

1.5 Report Outline

This thesis basically is divided into five chapters;

Chapter 1- Introduction

This chapter provides readers a first glimpse at the basic aspects of the research undertaken, such as overview wastewater treatment plan, problem statement, objectives, and scopes of this report.

Chapter 2- Review of literature studies

This chapter reviews the previous work of optimization technique, MPID tuning, and other reviews related to this project are presented.

Chapter 3- Methodology

This chapter presents the flow of the study and methodology being used in this study. Four types of MPID tuning which are Davison, Penttinen-Koivo, Maciejowski and Proposed Combined method will explain in this chapter. Implementation of optimization techniques in parameter tuning searching will also be included in this chapter.

Chapter 4- Results & Discussions

This chapter shows results of system performance by using MPID tuning of Davison, Penttinen-Koivo, Maciejowski and Proposed Combined method. It's also shows results of comparison and validation between two different optimization techniques. The results will be discussed thoroughly in this chapter.

Chapter 5- Conclusion & Future works

This chapter consists of conclusion based on the overall works and results. Included also some future works that can be done.

REFERENCE

[1] "Multivariable Control System Design," ed.

[2] M. W. I. * and S. Baskar, "Evolutionary algorithms based design of multivariable PID controller," *Expert Systems with Applications,* p. 9, 2009.

[3] T. N. L. Vu, J. Lee, and M. Lee, "Design of Multi-loop PID controllers based on the generalized IMC-PID method with Mp criterion," *International Journal of Control, Automation, and system,* vol. 5, p. 5, 2007.

[4] M. Seyedkazemi, "Desiging Optimal PID controller with Genetic Algorithm in View of Controller location in the Plant," *Proceedings of the 7th WSEAS International Conference on Signal Processing, Robotics and Automation (ISPRA '08),* p. 5, 2008.

[5] T. Slavov and O. Roeva, "Application of Genetic Algorithm to Tuning a PID controller for Glucose Concentration Control," *WSEAS Transactions on System,* vol. 11, p. 11, July 2012.

[6] "Design of Multi-Loop and Multivariable PID Controllers," ed, p. 39.

[7] R. Katebi, "Robust Multivariable Tuning Methods," in *PID Control in the Third Millennium, Advances in Industrial Control,*, R. Vilanova and A. Visioli, Eds., ed London: Springer-Verlag, 2012, p. 26.

[8] W. L. Luyben, "Simple method for tuning SISO controllers in multivariable systems," *Industrial & Engineering Chemistry Process Design and Development,* vol. 25, pp. 654-660, 1986.

[9] M. García-Alvarado, I. Ruiz-López, and T. Torres-Ramos, "Tuning of multivariate PID controllers based on characteristic matrix eigenvalues, Lyapunov functions and robustness criteria," *Chemical engineering science,* vol. 60, pp. 897-905, 2005.

[10] S. Gunnarson, V. Collignon, and O. Rousseaux, "Tuning of a decoupling controller for a 2x2 system using iterative feedback tuning," *Control engineering practise,* vol. 11, p. 7, 2003.

[11] S. Ginestet and D. Marchio, "Control tuning of a simplified VAV system: Methodology and impact on energy consumption and IAQ," *Energy and Buildings*, vol. 42, pp. 1205-1214, 2010.

[12] R. Ditmar, S. Gill, H. Singh, and M. Darby, "Robust Optimization-based Multi Loop PID Controller Tuning: A New Tool and its Industrial Application," *Control Engineering Practise*, p. 16, 2012.

[13] L. Campestrini and A. S. Bazanella, "Tuning of multivariable PID controllers through the Ultimate Point Method," 2006, pp. 1834-1839.

[14] M. Zhuang and D. Atherton, "PID controller design for a TITO system," 1994, pp. 111-120.

[15] A. Desbiens, A. Pomerleau, and D. Hodouin, "Frequency based tuning of SISO controllers for two-by-two processes," 1996, pp. 49-56.

[16] S. J. Shiu and S. H. Hwang, "Sequential design method for multivariable decoupling and multiloop PID controllers," *Industrial & engineering chemistry research*, vol. 37, pp. 107-119, 1998.

[17] N. A. Wahab, M. R. Katebi, and J. Balderud, "Multivariable PID Tuning of Activated Sludge Processes."

[18] N. A. Wahab, R. Katebi, and J. Balderud, "Multivariable PID control design for activated sludge process with nitrification and denitrification," *Biochemical Engineering Journal*, p. 9, 2009.

[19] R. Dittmar, S. Gill, H. Singh, and M. Darby, "Robust optimization-based multi loop PID controller tuning: A new tool and its industrial application," *Control engineering practise*, vol. 20, p. 16, 2012.

[20] R. Charaborty. (2010). *Fundamentals of Genetic Algorithms: Artificial Intelligent*. Available: www.myreaders.info/html/artificial_intelligence.html

[21] S. Voß, "Meta-heuristics: The State of the Art," *Lecture Notes in Computer Science*, p. 23, 2001.

[22] N. Yusuf, A. M. Zain, and S. Z. M. Hashim, "Evolutionary techniques in optimizing machining parameter: Review and recent application (2007-2011)," *Expert Systems with Applications*, vol. 39, p. 19, 2012.

[23] F. Glover and M. Laguna, "Tabu search," p. 18.

[24] X. Yang, "Metaheuristic Optimization," *Scholarpedia*, vol. 6, 2011.

[25] S. Das and P. N. Suganthan, "Differential Evolution: A Survey of the State-of-the-Art," *IEEE TRANSACTIONS ON EVOLUTIONARY COMPUTATION*, vol. 50, p. 28, 2011.

[26] K. Socha and C. Blum, "Ant colony optimization," ed, p. 28.

[27] X.-S. Yang, "Firefly Algorithm, Levy Flights and Global Optimization," in *Research and Development in Intelligent Systems XXVI*, M. Bramer, Ed., ed: Springer-Verlag, 2010.

[28] X.-S. Yang and S. Deb, "Cuckoo Search via L´evy Flights," *Proceeding of World Congress on Nature & Biologically Inspired Computing*, p. 5, 2009.

[29] N. Yusuf, A. M. Zain, and S. Z. M. Hashim, "Evolutionary techniques in optimizing machining parameters: Review and recent applications (2007-2011)," *Expert system with applications*, vol. 39, p. 19, 2012.

[30] B. Kumar and R. Dhiman, "Optimization of PID Controller for Liquid Level Tank System Using Intelligent Technique," *Canadian Journal on Electrical and Electronics Engineering*, vol. 2, p. 5, 2011.

[31] M. Rezaiee-Pajand and M. Mahdian, "A Genetic Algorithm for Structural Optimization," *Asian Journal of Civil Engineering (Building and Housing)*, vol. 3, p. 14, 2002.

[32] M. W. Iruthayarajan and S. Baskar, "Optmization of PID Parameters Using Genetics Algorithm and Particle Swarm Optimization," *IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007)*, p. 6, 2007.

[33] C. Li and J. Lian, "The Application of Immune Genetic Algorithm in PID Parameter Optimization for Level Control System," *Proceeding of The IEEE International Conference on Automation and Logistics*, p. 5, 2007.

[34] M. O. Ali, S.P.Koh, KH.Chong, S.K.Tiong, and Z. A. Obaid, "Genetic Algorithm Tuning Based PID Controller for Liquid-Level Tank System," *Proceedings of The International Conference on Man-Machine System (ICoMMS)*, 11 October 2009.

[35] P. Guo, X. Wang, and Y. Han, "The enhanced genetic algorithm for the optimization design," *2010 3rd International Conference on Biomedical engineering and infomatics (BMEI 2010)*, p. 4, 2010.

[36] Z. Jinhua, J. Jian, D. Haifeng, and W. Sun'an, "Self-organizing genetic algorithm based tuning of PID controllers," *Informations Sciences,* p. 11, 2009.

[37] D. Zhang and X. Yang, "Research on PID Control System Based on Genetic Algorithm," *Fourth International Conference on Machine Vision (ICMV 2011),* vol. 8350, 2012.

[38] J. Kennedy and R. Eberhart, "Particle swarm optimization," 1995, pp. 1942-1948 vol. 4.

[39] A. A. A. El-Gammal and A. A. El-Samahy, "A Modified Design of PID Controller For DC Motor Drives Using Particle Swarm Optimization PSO," p. 6, 2009.

[40] A. Jalilvand, A. Kimiyaghalam, A. Ashouri, and H. Kord, "Optimal Tuning of PID Controller Parameters on a DCMotor based on Advanced Particle Swarm Optimization Algorithm," *International Journal on "Technical and Physical Problems of Engineering" (IJTPE),* vol. 3, 2011.

[41] D. P. Rini, S. M. Shamsuddin, and S. S. Yuhaniz, "Particle Swarm Optimization: Technique, System and Challenges," *International Journal of Computer Application,* vol. 14, p. 7, 2011.

[42] P.-H. Chen, "Pumped-Storage Scheduling Using Evolutionary Particle Swarm Optimization," *IEEE Transaction on Energy Conversion,* vol. 23, p. 8, 2008.

[43] K.Valarmathi, D.Devaraj, and T.K.Radhakrishnan, "Particle Swarm Optimization based PI controller tuning for Fermentation Process " *Proceedings of the 2005 International Conference on Computational Intelligence for Modelling, Control and Automation, and International Conference on Intelligent Agents, Web Technologies and Internet Commerce (CIMCA-IAWTIC'05),* p. 6, 2005.

[44] C. Ou and W. Lin, "Comparison Between PSO and GA for Parameters Optimization of PID Controller " *Proceeding of the 2006 IEEE International Conference on Mechatronics and Automation,* p. 5, 2006.

[45] S.-F. Chen, "Particle swarm optimization for PID controllers with robust testing," *Proceeding of the Sixth International Conference on Machine Learning and Cybernatics, Hong Kong,* p. 6, 2007.

[46] T.o'Mahony, C. J. Downing, and K. Fatla, "Genetic Algorithm of PID Parameter Optimisation: Minimising Error Criter," p. 6.

[47] M. W. Iruthayarajan and S. Baskar, "Optimization of PID parameters using genetic algortmn and particle swarm optimization," *IEK-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES 2007)*, p. 6, 2007.

[48] A. Jalilvand, A. Kimiyaghalam, A. Ashouri, and M. Mahdavi, "Advanced particle swarm optimization-Based PID controller Parameters tuning," p. 7, 2008.

[49] H. Zhang, Y. Cai, and Y. Chen, "Parameter Optimization of PID Controllers Based on Genetic Algorithm," *2010 International Conference on E-Health Networking, Digital Ecosystems and Technologies*, p. 3, 2010.

[50] C. Li and J. Lian, "The Application of Immune Genetic Algorithm in PID Parameter Optimization for Level Control System," *Proceedings of the IEEE International Conference on Automation and Logistics*, p. 5, 2007.

[51] M. I. Menhas, L. Wang, M. Fei, and H. Pan, "Comparative performance analysis of various binary coded PSO algorithms in multivariable PID controller design," *Expert Systems with Applications*, p. 12, 2012.

[52] E. Atashpaz-Gargari, F. Hashemzadeh, and C. Lucas, "Designing MIMO PIID Controller using Colonial Competitive Algorithm: Applied to Distillation Column Process," p. 6.

[53] H.-C. Chen and S.-H. Chang, "Genetic Algorithm Based Optimization Design of A PID Controller for an Active Magnetic Bearing," *IJCSNS International Journal of Computer Science and Network ecurity*, vol. 6, p. 5, 2006.

[54] N. A. Wahab, M.R.Katebi, and J.Balderud, "Multivariable PID Tuning of Activated Sludge Processes," 2007.