MULTIVARIABLE PID TUNING USING CUCKOO SEARCH FOR ACTIVATED SLUDGE PROCESS

FINAL YEAR PROJECT

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APPROVAL

I hereby declare that I have been thoroughly read this report entitled Multivariable PID Tuning Using Cuckoo Search for Activated Sludge Process found that it has comply the partial fulfillment for awarding the Bachelor in Electrical (Control, Instrumentation and Automation) Engineering.

Signature : ....

Name of Supervisor : Nur Asmiza Binti Selamat

Date : ....

DECLARATION

I declare that this report entitled Multivariable PID Tuning Using Cuckoo Search for Activated Sludge Process is my original work and all references have been cited adequately as required by the University.

Signature : ....

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ABSTRACT

Designing a controller for wastewater treatment plant (WWTP) is important since the controller of the plant is usually neglected once the plant is commissioned. One of the latest optimization techniques is Cuckoo Search (CS). Therefore in this study, a Multivariable Proportional-Integral-Derivative (MPID) tuning using Cuckoo Search (CS) is applied to activated sludge process (ASP) model. The selected MPID to be used are Davison, Penttinen-Koivo, Maciejowski and Proposed Combine methods. The four type of MPID will be implemented to the ASP. Then the parameter of MPID tuning will be tune by two types of optimization techniques. The two optimization techniques used are CS and Particle Swarm Optimization (PSO). All MPID tuning result will be compared and analyses, from the result the best MPID will be chosen. The chosen MPID tuning will then be compared between CS and PSO in order to determine which optimization techniques are better.

ABSTRAK

Penciptaan pengawal untuk loji rawatan air (WWTP) penting kerana pengawal loji rawatan air selalu diabaikan sebaik sahaja loji itu mendapat kelulusan. Salah satu teknik pengoptimuman yang baharu ialah *Cuckoo Search* (CS). Oleh itu dalam pengajian ini, penalaan *Multivariable proportional-integral-derivative* (MPID) menggunakan *Cuckoo Search* (CS) akan diadaptasi kepada model proses rawatan air kumbahan (ASP). Pengawal MPID yang dipilih untuk digunakan dalam kajian ini adalah metod *Davison, Penttinen-Koivo, Maciejowski dan Proposed Combine*. Kemudian, paramater keempat-empat pengawal MPID akan diperoleh menggunakan dua jenis teknik pengoptimuman. Teknik pengoptimuman tersebut adalah CS dan *Particle Swarm Optimization* (PSO). Semua hasil perolehan MPID akan dibandingkan dan dianalisis, MPID yang terbaik akan dipilih berdasarkan perolehan tersebut. MPID yang terpilih itu kemudiannya akan dibandingkan pula antara CS dan PSO untuk memastikan teknik pengoptimunan manakah yang terbaik.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

The activated sludge process (ASP) is a technology that is used in a wastewater treatment plant (WWTP), to biologically remove organic pollutant from wastewater. This process involves a number of interacting controls. Once the plant been commissioned, the controllers are remained as it is. Therefore, the environment conditions are seen to affect the performance of WWTP producing high quality effluent. With an effective and proper tuning of multivariable PID tuning, the performance of WWTP will improves. Cuckoo Search technique will be used in this study to obtain the parameter tuning.

1.2 Problem Statement

At the present time, most of the industrial processes are in multivariable system. Since the systems are more complex, controlling multivariable system using Single-input Single-output (SISO) is more difficult. Therefore, more and more research is being done to adapt multivariable processes into the multivariable systems. However, to obtain a proper parameter tuning using either SISO or multivariable process is crucial. Manual trial and error method is still being used to acquire the parameter tuning in PID. The method is considered to be tedious, time consuming and not guarantee to give the best system performance. Thus, tuning parameter based on optimization techniques were proposed in this study.

1.3 Objectives

The objectives of this project include:

1) To implement the Multivariable PID (MPID) control method to Activated Sludge Process.
2) To apply the optimization techniques, Cuckoo Search (CS) and Particle Swarm Optimization (PSO) for MPID control tuning for Activated Sludge Process (ASP).
3) To compare the system performance between using Cuckoo Search (CS) and Particle Swarm Optimization (PSO).

1.4 Scope of Study

This project use MPID controller design for activated sludge process. Four types of MPID tuning will be used which are Davison, PenttinenKoivo, Maciejowski and Proposed Combined method. The scalar parameter MPID controllers are then being tune by optimization method such as CS and PSO. Only basic CS and PSO algorithm are implemented in the system. The simulation of this project is done using MATLAB/SIMULINK software.

1.5 Project Report Overview

This section provides a brief outline of the chapters included in this report.

Chapter 1 Introduction

This chapter provides the basic aspect of the project and indicates the project's background, objectives, problem statement and scopes.

Chapter 2 Literature review

In this chapter, the concept and previous work of related literature studies are being reviewed. Among the reviewed studies are the optimization techniques, ASP controllers and MPID tuning.

Chapter 3 Methodology

This chapter presents the flow and methods that are being used to accomplish the project. There are four types of MPID tuning will be explained in this chapter which are Davison, Penttinen-Koivo, Maciejowski and Proposed Combined method. The modeling of ASP in mathematical equation is also shown.

Chapter 4 Results and Discussion

This chapter shows the results of the system performance by using MPID tuning method. Its scalar parameter is being tuned by CS and PSO. The results are compared and will be discussed in this chapter.

Chapter 5 Conclusion and Future works

This chapter is about the conclusion based on the overall works and results. There is also a mention for some future works that can be done.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discuss about brief definition of related subject or issues for the project. From this review, a several MPID methods and optimization technique will be selected for further studies. This chapter also summarizes the related previous researches that have been done.

2.2 Activated Sludge Process

Activated sludge process is still the most widespread used system for biological wastewater treatment plant [1]. It comprise of a biological process to convert or breakdown organic or inorganic matter to treat wastewater, which will produce a quality effluent. This process operates on the principle that as microorganisms grows, they develop into sludge [2]. This sludge is then settled to the base of the tank, result in a relatively clear liquid free of organic material and suspended solids. As previously described, activated sludge process is divided into two parts, an aeration tank which where the microorganisms grow (biochemical stage) and a settling tank, in which a liquid free of organic material is accumulated (physical stage) [3].

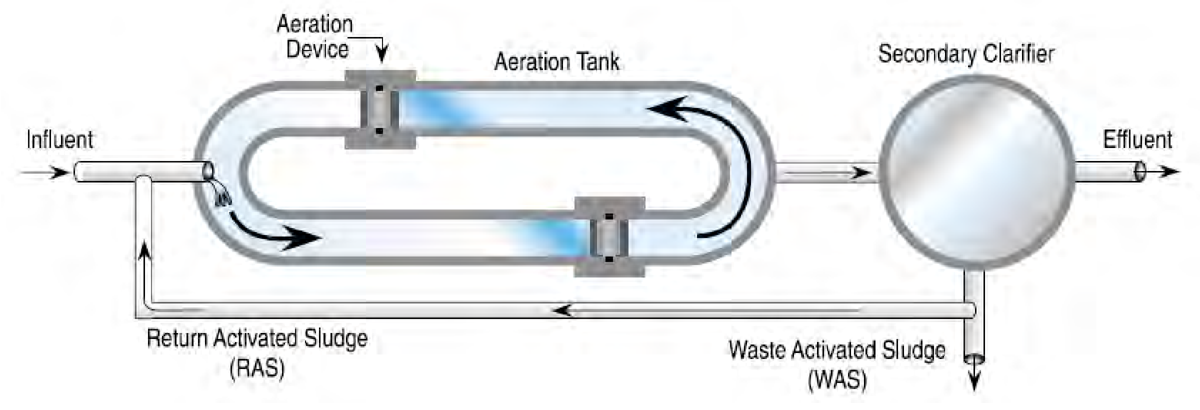

Figure 2.1: Activated Sludge Process

A flow of activated sludge process is shown in Figure 2-1, from the figure, the incoming input of the system or influent is directed to the aeration tank. The aeration tank along with aeration device will facilitate the condition of an aerobic and continuous flow for the microorganisms. The process is continued in the secondary clarifier. As the microorganisms break down organic matter in wastewater, it forms a floc, which is then left to settle to the base of tank. After a specific amount of treatment time, a clarified effluent is produced and only a portion of settled floc is recycled back to the aeration tank. It is to maintain the right concentration of microorganisms in the aeration tank.

2.3 Activated Sludge Process Controller

Among the types of wastewater treatment plant (WWTP), the ASP is one of the most popular methods to biologically remove organic components, nitrogen and phosphorus from the treated water [4]. From the automatic control perspective, ASP has been a widely case of study, for example by Nejjari [5] a parameter and state non-linear estimator is used in an adaptive linearizing control of the dissolved oxygen and substrate concentration of an ASP but under the assumption that only the dissolved oxygen is available for measurement.

A previous study done by Norhaliza [6] is about several multivariable PI control methods are applied to the ASP by linearizing the non-linear model and the results are presented, as well as the combination of some of these methods. A research by Caraman [7], predictive control is used to maintain a low concentration of substrate at the output by controlling the dissolve oxygen using the dilution rate. The internal model of the predictive control is a three layer neural network.

As stated by Koumboulis [8], the control of the substrate concentration is achieved using an estimation based on the dissolved oxygen measurements, a dynamic controller that cope with the change in reference and a PID controller that corrects the steady state error produce by the use of a linearized model in the first controller. Vilanova [9], a decentralized PI approach is presented to show that simple well tuned PI controllers can achieve a similar performance than more complex methodologies for the ASP case.

Rojas [4], the Virtual Reference Feedback Tuning (VRFT) is applied to the control of the dissolved oxygen and substrate concentration output in ASP based wastewater treatment using an Internal Model Control structure. This data driven methodology was found to be easy to implement and gave excellent results when compared to a two degrees of freedom continuous time PI controller, but with the advantage of using only data taken directly from an experiment in open-loop and skipping the modeling step.

2.4 Multivariable PID

(MIMO) stands for multiple-inputs multiple-outputs, otherwise known as multivariable processes, defined as either having more than one input variables or more than one output variables. A set point is given to input variables that needed to be controlled. There are a number of ways for control variables to be manipulated by the controller function to control these variables. This process might be difficult to control if a process interaction exists.

Process interactions possess two main problems to control a multivariable process if it is not being managed by the multivariable controller. Only a change in one desired value will make the response to the output variables to vary. It is not a direct process from one input variable to the output variables [10]. For example, in a single loop PID control, the controller of that process must examine the multivariable process with all control loops. This process will make the PID controllers difficult to tune.

The typical method to control a multivariable process is using single loop control where one controller is used to control each loop separately. The control system structure is shown in Figure 2-2, where the system is represented by transfer function (1). The process shown in Figure 2-2 has two input variables and two output variables. Therefore, it is named as a two-by-two (2x2) multivariable process. An interaction effect is shown in equation (2) and equation (3).

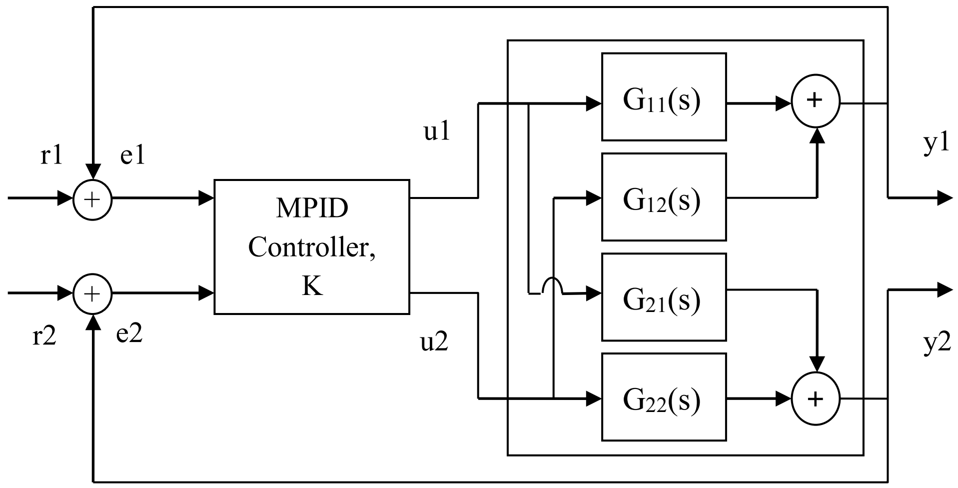

Figure 2.2: Single loop control for multi input multi output system with PID

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} G_{11}(s) & G_{12}(s) \\ G_{21}(s) & G_{22}(s) \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \tag{1}$$

$$y_1 = u_1 G_{11}(s) + u_2 G_{12}(s) \tag{2}$$

$$y_2 = u_2 G_{22}(s) + u_1 G_{21}(s) \tag{3}$$

2.5 Multivariable PID Tuning for Activated Sludge Process

Multivariable PID tuning can be categorized to parametric and non-parametric methods [11]. BLT, gain and phase margin, minimum variance control, internal model control and robust decentralized method are example of parametric tuning, while Davison, PenttinentKoivo and Maciejowski can be categorized as nonparametric methods.

Several studies have been made on multi-loop PID control [12] Luyben utilized a simple multi-loop PID tuning method in multivariable systems with no consideration for the interaction. A decentralized PID controller design for two-input two-output (TITO) systems, in which the desired critical point is used to tune the PID controller by the Ziegler-Nichols rule or their modification is proposed by Palmor. While Wang works on a decentralized PI/PID controller tuning with a lead-lag decoupler for TITO processes.

A decoupled PI controller for TITO processes with interacting loops has the advantage to reduced the interaction substantially by using set-point weighting is developed by Astrom. Moreover, Huang presented a method of diagonal PID controller design based on internal model control (IMC) for multivariable temperature control system. Davison, Penttinen-Koivo and Maciejowski methods are based on step tests or frequency responses at a single point [6]. For Davison method decouples the system at low frequency. Extensions from Davison method are resulting Penttinen-Koivo method, which diagonalized at high frequency. While for Maciejowski decouple the plant at bandwidth frequency.

2.6 Optimization Technique

A target for optimization design would probably be the same meaning as lean production, which is to operate with minimum possible resources with maximizing the amount of work accomplished. An optimization algorithm works by iteratively execute procedure in comparing current with previous solutions until the best possible solution is establish.

By means of computers, optimization techniques have develops into a computer-aided design activities. The two most widely used optimization algorithm types are deterministic algorithms and stochastic algorithms. Deterministic algorithms make use of certain rules for moving from one solution to other solutions. These algorithms are used in some situation and proved to be successfully implemented in many engineering design problems. While for the stochastic algorithms, it is characterized on probability translation rules. These algorithms are becoming more popular as it has particular properties which deterministic algorithms do not possess. [13].

Metahueristics algorithms are a part of stochastic algorithms. These algorithms were design to overcome complicated optimization problems where other optimization techniques are being unsuccessful to be implemented. These metahueristics algorithms have been recognized to generally be the most realistic methods to solve a lot of real-world problems that were compatible with nature. The effectiveness and general applicability are the advantages of metahueristics algorithms. Metahueristics algorithms approach in solving a problems are begin by generating an initial solutions and from that, it will start to improves the search with the guide of certain principle.

One of the earliest metaheuristics is simulated annealing (SA) by Kirkpatrick [14], which is motivated by the physical annealing process, but within the framework here simply specifies a methods for determining if a solution should be accepted. Tabu search is another popular metaheuristics by Glover. The defining characteristic of Tabu search is in how solutions are selected from the neighbourhood.

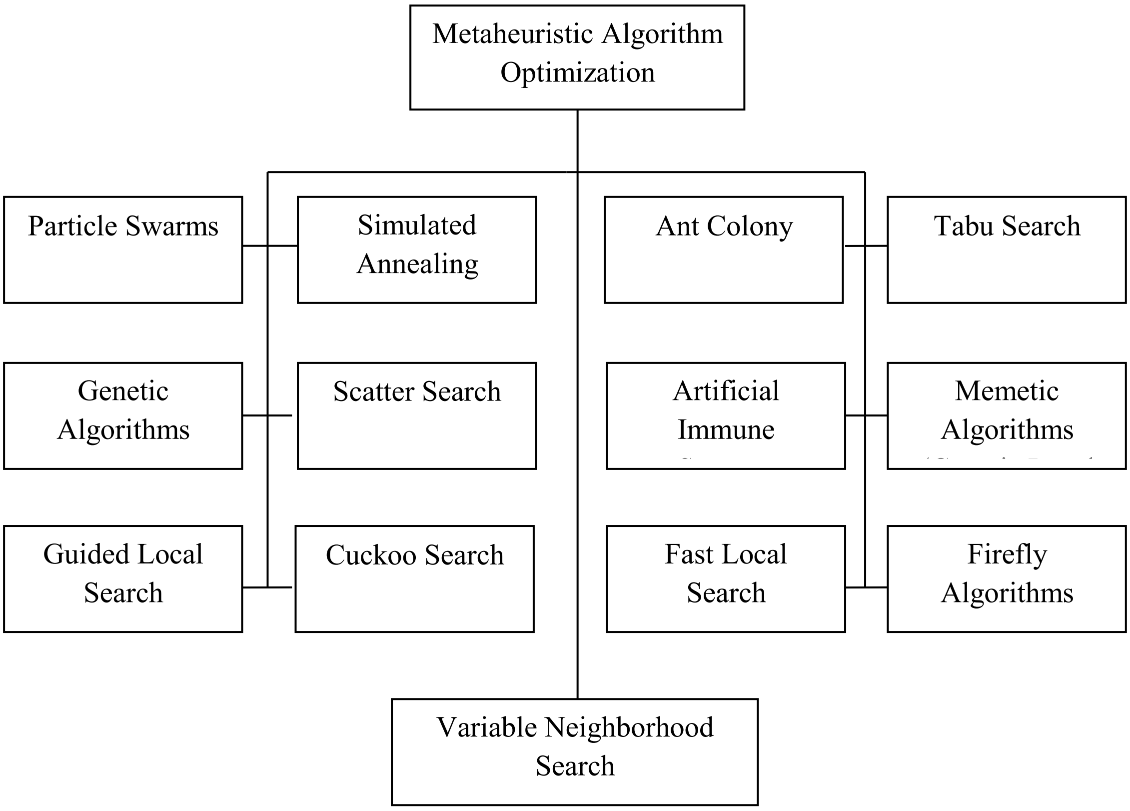

Figure 2.3: Metaheuristic Algorithm for Optimization

2.7 Multivariable PID Tuning using Optimization Technique for Activated Sludge Process

There has been a research for ASP using optimization technique by Norhaliza [6] which study the implementation of MPID controller to a process for wastewater treatment. For this study, four MPID control methods are analyzed which is made up of Davison, Penttinent-Koivo, Maciejowski and a Proposed method. All of the methods are suitable for MIMO control loops that experience loop interaction. These methods only require a simple pant models. The performance of each method is measured up based on a nonlinear benchmark model and the scalar tuning parameter values are obtained using optimization methods. From the results of simulation, it shows the significance of the study and proves that the proposed methods produce better results than the other three methods with respect to decoupling capabilities and closed-loop performance.

2.8 Cuckoo Search

Cuckoo Search (CS) is a new metahueristic algorithm developed in 2009 by Xin-She Yang and Suash Deb. This algorithm is based on some cuckoo species. It is improved further by the addition of Levy flights. CS is potentially far more efficient than PSO and genetic algorithms as revealed in recent studies [15].

Cuckoo is a fascinating bird, they have an aggressive reproduction strategy. They lay their eggs in other species of birds nest and sometimes to increase the hatching probability of their own eggs, they removed the eggs of the host birds [16].

To ease the description of the standard Cuckoo Search, it is best to set or follow three idealized rules [15]. Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest. The best nests with high quality eggs will be carried over to the next generations. The number of available host nests is fixed, and the egg laid by a cuckoo is discovered by the host bird with the probability$\rho_a \in (0,1)$. In this case, the host bird can either get rid of the egg, or simply abandon the nest and build a completely new nest.

2.9 PSO

Particle swarm optimization (PSO) is another metahueristic algorithm developed in 1995 by Kennedy and Eberhart. This algorithm is a randomly determined based optimization approach. [19] This algorithm is based on the behavior from group of animals that herd or gather such as flocking of bird and schooling of fish.

Naturally, a group of animals will randomly search for food, and once a member of the group found a food source (potential solution), others will tag along. The groups attain the best food source by simultaneously communicates with other member of the groups which has a better food source. The member who has the better condition will notify its groups so that the whole groups can move to that place. The process of food searching may occur repetitively until the best food source is discovered. [20].

For PSO algorithm, it is based on the same process of this group of animal's behavior. Particle swarm optimization consists of a swarm of particles, where a single particle will represent a potential solution. From the creation of PSO until the recent times, there have been a several modifications. The modification made to the original PSO is to improve the time taken to achieve the best conditions. From the development of PSO algorithm, it will give more advantages in using this method to solve a problem.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter contains of the methodological issues that used in this project. The main purpose of this chapter is to collect information that related to the methods and techniques that have been used in this project development, such as process of research, process of identifying, and result.

3.2 Flow of the study

As to develop a project, a flow chart is to be used in order to keep the process of development the project is on the right track. The first action to be taken is the selection of a proper title from the offered title list. Then with the guide from supervisor, the objectives, scope, methodology and outline of the project are determined. To be able to continue progressing in the project, there is a need to collect as many as possible previous research and information that is related to this project. From the collected information, a literature review is done to get the general overview on each subject related to this project. The most reliable previous research for ASP modeling is then chosen to be used in simulation.

Once reviewing MPID tuning past research and journal, there are four methods that are selected to be applied in this project. The four methods are considered to be the appropriate choice, which are Davison, Penttinen-Koivo, Maciewjowski and Proposed Combine method. Before, there are already a few optimization technique is being used in ASP control modeling. Therefore, the same optimization techniques will also being implemented to compare with the selected optimization technique. The previous technique was PSO, while the selected technique is CS.

Once all the related subject in this project were all determined, it is time to develop the software part to simulated the response of ASP. And the produced result will be analyzed and discussed. A conclusion will be made from all the work in this project.

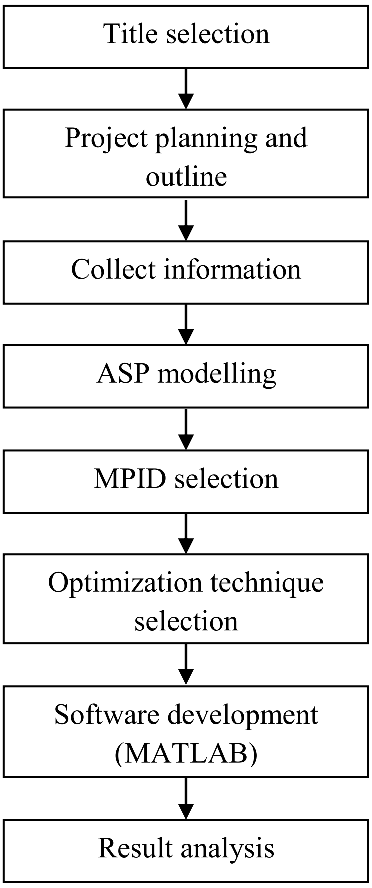

Figure 3.1: Methodology flowchart