ANALYSIS AND DESIGN OF A LINEAR INPUT/OUTPUT DATA-BASED PREDICTIVE CONTROL

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This thesis is dedicated to my beloved father, mother, friends and lecturers. There is no doubt in my mind that without their continued support I could not have completed this process.

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ABSTRACT

A subspace identification algorithm is reformulated from a control point of view. Model Predictive Control (MPC) is defined as a category of control system that determines the control trajectory that will result in an optimized future behavior of a plant. Typical design of predictive controllers starts with identification of parametric model using plant input and output data. Then, predictor matrices can be obtained from the model. Next, the predictor matrices are used to obtained predictions for the process output which are used in the controller design. In this work, however, the predictive controller can be obtained directly from input and output data by using the subspace matrices. Therefore, this method eliminates the intermediate step of parametric model identification. The comprehension of this concept is discussed and the implementation of predictive controller is done virtually by using MATLAB simulation. The proposed linear input/output data-based predictive controller is applied to the property control of an activated sludge plant. A typical control problem such as variation of set-point tracking has shown that the proposed controller demonstrates satisfactory control performance.

ABSTRAK

Algoritma *subspace* dirumuskan semula dari perspektif sistem kawalan. Model peramal kawalan ditakrifkan sebagai satu kategori sistem kawalan yang menentukan unjuran kawalan yang akan menghasilkan tingkah laku akan dating yang optimal bagi sesuatu sistem. Reka bentuk kebiasaan model peramal kawalan bermula dengan pengenalpastian kepada model parametrik yang menggunakan input dan output data sesuatu sistem. Kemudian, matriks ramalan boleh diperolehi daripada model tersebut. Seterusnya, matriks ramalan ini digunakan untuk meramal output proses dan kemudian digunakan dalam reka bentuk model peramal. Walau bagaimanapun, dalam projek ini, pengawal ramalan boleh diperolehi secara langsung daripada input dan output data dengan menggunakan matriks *subspace*. Oleh itu, kaedah ini telah menghapuskan langkah perantaraan iaitu langkah untuk mendapatkan model parametrik. Kefahaman konsep ini akan dibincangkan dalam laporan ini dan pelaksanaan pengawal ramalan dilakukan dengan menggunakan simulasi MATLAB. Pengawal linear input dan output data yang dicadangkan daripada penyelidikan ini dilaksanakan ke atas proses lumpur aktif dan sifat kawalan ke atasnya diperhatikan. Masalah umum kawalan seperti menjejaki variasi aras had telah menunjukkan bahawa pengawal yang dicadangkan mempunyai prestasi kawalan yang memuaskan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BOD	-	Biochemical Oxygen Demand
CVA	-	Canocical Variate Analysis
DMC	-	Dynamic Matrix Control
LQG	-	Linear Quadratic Gaussian
MBPC	-	Model-Based Predictive Control
MIMO	-	Multi-Input Multi-Output
MPC	-	Model Predictive Control
N4SID	-	Numerical Algorithms for Subspace State Space System Identification
PRBS	-	Pseudorandom Binary Sequence
QP	-	Quadratic Programming
SISO	-	Single-Input Single-Output
SPC	-	Subspace Predictive Control
SVD	-	Singular Value Decomposition
WWTP	-	Wastewater Treatment Plant

LIST OF SYMBOLS

B^{+}	-	The Moore-Penrose pseudo-inverse of B
$B^{\perp}$	-	The orthogonal complement of B
$\dot{C}$	-	Recycled biomass
F	-	Frobenius norm
H_N	-	The deterministic lower triangular block-Toeplitz matrix
H_{NS}	-	The stochastic lower triangular block-Toeplitz matrix
J	-	Quadratic cost function
K_c	-	Saturation constant
K_s	-	Growth rate
L_u	-	Controller parameters
L_w	-	Controller parameters
r_k	-	The reference outputs
$\dot{S}$	-	Substrate
U_f	-	Block Hankel matrices consisting of the future input
U_p	-	Block Hankel matrices consisting of the past input
u_k	-	The future control input
V_f	-	Block Hankel matrices consist of measurement noises
W_p	-	Short-hand notation related to the past inputs and outputs
X_f	-	The future state sequence
$\dot{X}$	-	Biomass
$\dot{X}r$	-	Dissolved oxygen concentrations
Y_f	-	Block Hankel matrices consisting of the future output
Y_p	-	Block Hankel matrices consisting of the past output

$\hat{Y}_f$	-	The linear predictor
$\hat{y}_k$	-	*k-step-ahead* predicted output
Z_f	-	Block Hankel matrices consist of process noises
μ	-	Monod law
Γ_N	-	Extended observability matrix

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of project

In recent years, many modern control methods use an artificial model to design a control system. One of them is model predictive control. A model predictive control (MPC) is known as an advanced controller especially in process control. When the controller is based on a good model reference and a reasonably accurate state estimate, it can show outstanding control performance. MPC is defined as a category of control systems that determine the control trajectory that will result in an optimized future behavior of a plant [1]. The control trajectory can be determined within a fixed time-frame and the whole optimization procedure can be subjected to constraints in the input or output variables.

The proposed linear input/output data-based predictive controller is applied to the property control of an activated sludge. The activated sludge is one of the most extensively used biological wastewater treatment processes [7]. Due to the interest in high effluent quality and in reduction of energy consumption, controlling this bioprocess has captured many researchers' attention. The biological process is described by a set of non-linear equations obtained from mass-balance considerations. The implementation of designed input/output data-based predictive controller will be performed simulation using MATLAB. The simulation will demonstrate its improved performance by applying various conditions.

1.2 Problem statement

In real world application, there is a number of controllers use in process control. This work focuses on model predictive controller, which is among the advance process controller. Most researchers focus on these two trends of research; identifying a model from a given the data or finding a controller from a given plant model. In fact, system identification and model-based control are very much related. Typically, controller will be design based on the plant model which obtains from identification process. This method is call model-based predictive control. However, in such method which develops by [2], the step of identification process can be skipping; hence, it is called model-free controller design. Under some constrain, especially in minimizing operation cost in terms of time, design of predictive controller based on input/output data become important. Consequently, this work will reformulate the system identification step by develop a method that allows for the calculation of a controller directly from the input/output data – so-called input/output data-based predictive control.

1.3 Objectives of the project

The main objective of this project is to reformulate a subspace identification algorithm into a control point of view. The proposed controller should be able to achieve typical control objective i.e., set-point tracking.

(i) To design predictive controller

(ii) To applied proposed controller into an activated sludge plant

1.4 Scope of the project

The scope of the project includes:

(i) To study subspace identification algorithm from input/output data.
The identification process starts with constructing subspace matrices from input/output data. Then, apply a subspace algorithm which is numerical algorithms for the subspace state space system identification (N4SID).

(ii) To study algorithm of predictive controller.
Control strategy which makes an explicit use of a process model in a cost function minimization to obtain the control signal.

(iii) To study mathematical model for an activated sludge plant.
The biological process is described by a set of non-linear equations obtained from mass-balance considerations.

(iv) To simulate the controller performance using MATLAB.
The system is constructed using Simulink block diagram which contain plant operation, input/output, and system equation. The controller algorithm is written in separate m-files.

1.5 Methodology

The method used to conduct this research is illustrated in Figure 1.1. This research starts with acquiring basic knowledge of an activated sludge plant. From this study, non-linear equations of the activated sludge plant are obtained. Then, subspace identification and predictive control algorithm are derived. Computer simulation is done base on non-linear system equations and these algorithms derivation. The simulation results are analyzed and modifications in controller tuning parameters are done if necessary to get good control performance. Finally, the thesis is written at the end of this project.

1.6 Thesis outline

This thesis consists of five chapters. Chapter 1 is about the background of project, problem statement, objective and scope of the project, and research methodology. This chapter gives general overviews of the research carried out.

Chapter 2 presents some reviews on activated sludge process and input/output data-based predictive control. This chapter describes research that has been done in subspace predictive control. Also, it describes the non-linear equations of the activated sludge plant

Chapter 3 shows in details the derivation of subspace identification and algorithm of predictive controller. It describes step-by-step subspace predictive controller design.

Chapter 4 shows how the computer simulation is done using MATLAB. The results obtained are discussed and analyzed in this chapter.

Chapter 5 provides the conclusion for this project. This section is summarized the whole work that has been done through out this research. It also gives some suggestion of further research which can be carried out.

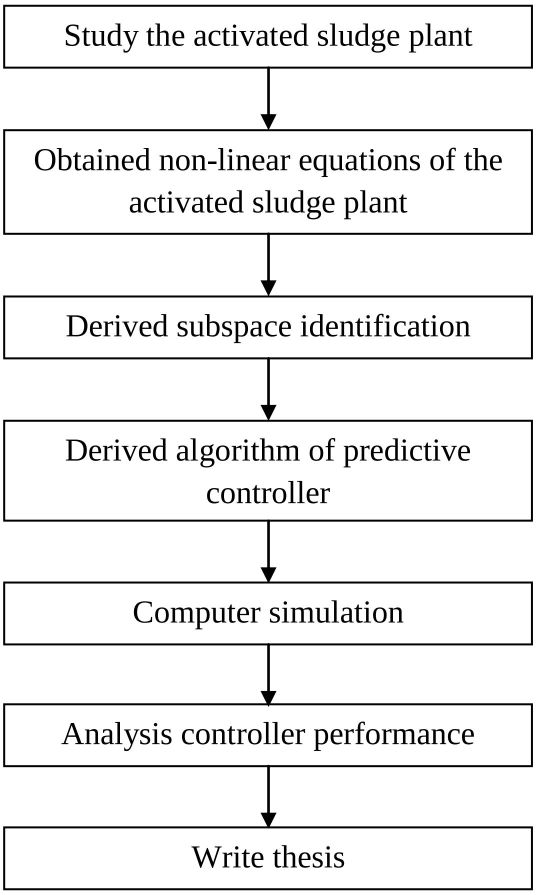

Figure 1.1: Project flowchart

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