SIGNIFICANCE OF POLE, ZERO, DELAY AND INTEGRATOR IN PROCESS MODELLING OF SYSTEM

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A report submitted in fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering (Plant & Maintenance)

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DECLARATION

I declare that this project report entitled “Significance of Pole, Zero, Delay and Integrator in Process Modelling of System” is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant & Maintenance).

Signature : ……………………………………

Supervisor's Name : ……………………………………

Date : ……………………………………

DEDICATION

I hereby dedicate this to Associate Professor Ir. Dr. Md Fahmi for his advice, his faith, and his patience in me, as well as the unconditional love and support of my parents throughout my journey towards the completion of this project.

ABSTRACT

System identification is an approach of constructing mathematical model of a dynamical system using the instrumentation signal of input and output of the system. Among the choices of model in system identification is process model. Within the model, the presence of pole, zero, delay, and integrator may easily be incorporated. This project investigates the significance of these components in the transfer function of process model by analysing the result of process model estimation of 3 simulated systems to grasp a better understanding of their respective influence before moving on into analysis of process model result of a real industrial data of air compression system. The proposed methodology of this project involves the data import and pre-processing until the end of simulation and validation stages. The outcome of the simulation would undergo analysis and discussion to determine the significance of pole, zero, delay, and integrator in systems based on simulated and real industrial data. As results, the order of a system is indirectly reflected by the number of poles within a model, while zero affects the stability and step response of a system. Significance of delay is dependent on the nature of the system whereby a time lag exhibits to reach an optimum operating level. Lastly, integrator contributes in trend prediction of a system by restricting the range of model estimation from going out of track.

ABSTRAK

Identifikasi sistem merupakan sebuah pendekatan untuk membina model matematik daripada sistem dinamik dengan menggunakan isyarat instrumentasi input dan output daripada sistem tersebut. Antara pilihan model dalam identifikasi sistem ialah model proses. Dalam model, terdapat kutub, sifar, penunda, dan penyepadu yang bekerjasama antara satu sama lain. Projek ini bertujuan untuk menyiasat kepentingan komponen ini dalam fungsi pemindahan model proses dengan menganalisis hasil anggaran model proses 3 sistem simulasi untuk pemahaman yang lebih lanjut atas pengaruh masing-masing sebelum beralih ke analisa hasil model proses data industri sebenar, iaitu sistem pemampatan udara. Metodologi yang dicadangkan bagi projek ini melibatkan pengimportan data dan pra-proses sehingga tamat peringkat simulasi dan pengesahan. Hasil simulasi akan melalui analisa dan perbincangan untuk menentukan kepentingan kutub, sifar, penunda, dan penyepadu dalam sistem berdasarkan data simulasi dan data industri yang benar. Sebagai hasil, susunan sistem secara tidak langsung dicerminkan oleh bilangan kutub dalam model, manakala sifar mempengaruhi kestabilan dan tindak balas langkah sistem. Kepentingan penunda bergantung pada sifat sistem yang mempunyai ketinggalan masa untuk mencapai tahap operasi yang optimum. Akhir sekali, penyepadu menyumbang dalam ramalan arah aliran sistem dengan mengehadkan julat anggaran model daripada keluar dari landasan.

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LIST OF ABBREVIATIONS

AR	-	Autoregressive
ARMAX	-	Autoregressive-Moving Average with Exogenous
ARX	-	Autoregressive with Exogenous
AST	-	Accelerated Stress Test
FIR	-	Finite Impulse Response
FPE	-	Final Prediction Error
GUI	-	Graphic User Interface
LHF	-	Left-Half-Plane
LOESS	-	Locally Estimated Scatterplot Smoothing
MSE	-	Mean Squared Error
PSM	-	*Projek Sarjana Muda*
RHP	-	Right-Half-Plane
SCADA	-	Supervisory Control and Data Acquisition
SI	-	System Identification
SOFC	-	Solid Oxide Fuel Cells

CHAPTER 1

INTRODUCTION

1.1 Background

System identification is the construction of mathematical models from observed data of a dynamic system. A dynamic system is a system with memory which reacts with inputs of what is done previously. Mathematical roles are having increasingly important roles in the science and engineering of today, whereby among the solution of tasks involved simulation, control design and proper signal processing. It is important to master various techniques for model building and there are two general ways to model a dynamic system. First-principles modelling is by using the knowledge of physics or math behind a problem to form a model, whereas the data-driven modelling is by using measured data from a system to construct a model.

System Identification (SI) falls into the category of data-driven modelling. A system, for example, is a real thing like an indoor cooling system with input signals via thermostat and temperature sensors and outputs to be humidity and room temperature, whereby it is influenced by error, disturbance and outer environment. A model is an object where a real system is replaced with mathematical expressions. These expressions create an approximate relationship between the input signals and the output signals. Within the expressions representing the model, there are uncertainties in parameters. Hence, a wide variety of model structure is covered by SI in order to acquire a higher accuracy of system estimation. The model structure which this project is covering will focus on process modelling.

A continuous-time transfer function is the structure of a process model which defines the linear system dynamics in terms such as static gain, time constants, process zero, time delay, and enforced integration. Many industries are using process models to describe system dynamics as it could be applied to a wide variety of production environment due to its simplicity, transport delay estimation support, and easy interpretation of poles and zeros coefficients on the model. Different model structures could be created by altering the number of poles and zeros, and the participation of delay and integrator.

A modelling approach involves finding of known constants and fixed parameters following from equipment dimensions, constant physical and chemical properties and so on (Mikles and Fikar, 2007). This include the determination of significance of the delay and overshoot of a system. Most if not all of the dynamic systems encountered will have amount of time delay inherent to it. A significant amount of delay will either degrade the performance or make the system to be unstable, as the delay is subjected as old information to determine the current output of the controller. Meanwhile, not all process in the industry is suitable with the occurrence of overshoot. For example, an overshoot in temperature output of a chemical process causes disruption or reaction between molecular particles. Integrator serves as an output block with respect to time to prevent the values of output from exceeding specifiable levels. Accuracy of the model is improved via integrator when the range of overshoot data is limited down to a desirable range of data levels. Thus, old information taken into account during determination of current output has a lower tendency of disturbance or being unstable in the future. Hence, the goal of this project is to determine the influence of poles, zeros, delay and integrator on the search to obtain the best fit model suited for the system according to the data set given.

1.2 Problem Statement

Problems raised during predictive and preventive control of a dynamical system are commonly solved via System Identification. Preferred outputs with the characteristics needed to be embedded within a system could be predicted using the best fit mathematical model. In process modelling, the number of poles and zeros, and the existence of delay and integrator which may easily be incorporated are determined by the user. To achieve the best fit model, it is crucial for users to know the effects of each parameters. Therefore, the ability to understand the significance of these components in the transfer function to obtain the best fit process model is essential for the industrial system.

1.3 Objective

The objectives of this project are as follows:

i. To perform system identification using process model.

ii. To investigate the effect of different number of poles in process model.

iii. To investigate the significance of zero, delay and integrator in process model.

1.4 Scope of Project

The scopes of this project are:

i. This project will focus on the method of applying process model for system identification.

ii. This project requires utilisation of MATLAB software as simulation tool.

iii. This project aims to solve a single input - single output (SISO) system.

iv. Analysis on the behaviour of dynamical system and the mathematical modelling will be carried out based on best-fit index, final prediction error, and mean squared error.

1.5 General Methodology

The actions to be taken to obtain the objectives in this project are as below:

1. Literature Review

   Journals, articles, or any related informative materials regarding this project are reviewed to achieve adequate knowledge and understanding.

2. Trial Run with MATLAB's Toolbox

   A transfer function of process model is built from a sample data set. Performance of the transfer function of process model will be analysed.

3. Data Acquisition

   An industrial real-time data is needed to create a robust mathematical model. Data is provided by supervisor after the succession of trial run on SI using sample data of MATLAB.

4. Simulation of SI using Process Model

   Data set is replaced with real-time industrial data provided by supervisor via skillsets of mathematical model technique obtained from past trial run.

5. Analysis and Discussion

   Analysis are presented by analysing and validating the performance and quality of the mathematical model derived from simulation.

6. End Reporting

   A project report is written after the analysis of project is completed.

The methodology of this study is summarised in the flow chart as shown in Figure 1.1.

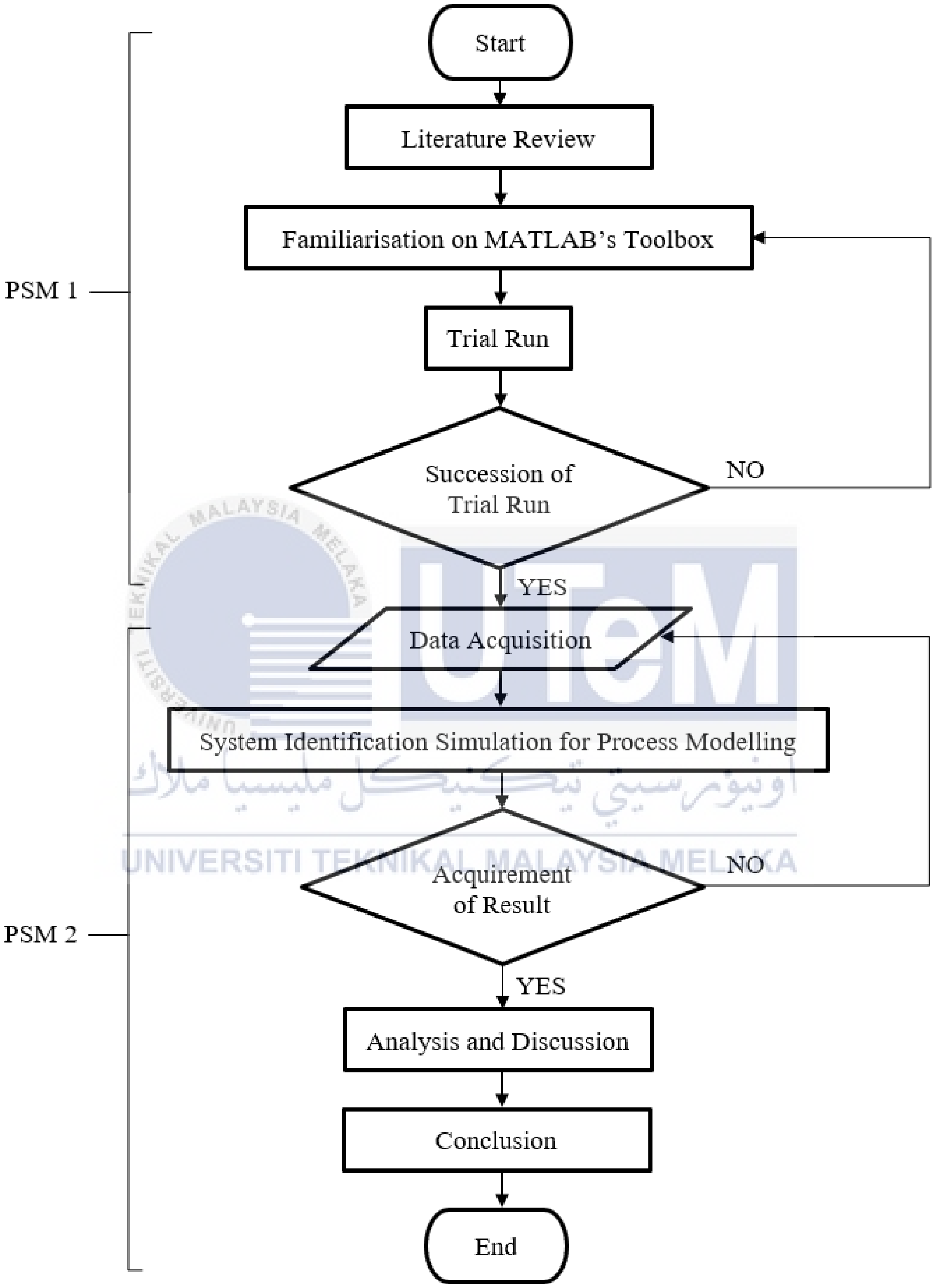

Figure 1.1: Flow chart of general methodology

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review will focus on the discussion of three keywords regarding the research title: Process Model, Transfer Function and System Identification. This chapter serves as foundation of knowledge for the upcoming chapters of methodology and analysis of project report. References related to the research topic and field are summarised in this chapter.

2.2 System Identification

Systems are usually referred as mechanism that generates an output by taking in input, whereby system response is the relationship of the output related to the input. The relationship between the system input and the system output could be modelled using mathematical equation, which is the transfer function in this case of study.

2.2.1 Mathematical Model

Ljung (1987) stated that relationships between system variables using mathematical descriptions could be described via mathematical models. Mathematical descriptions used such as differential equations could be further explained through different aspects such as linear or non-linear, continuous-time or discrete-time.

Mathematical models could be generated through construction of block diagram using first principles. The alternative way to generate mathematical models is through graphical models which are experimental based, which is also known to be system identification. Observation of data is needed using this method to obtain the input and output signals before carrying out data analysis to form a model.

2.2.2 Definition of Dynamical System

A system is defined as an object with variables interacting with each other to produce output signals. Disturbances are variables which could not be controlled and it could be classified as either a measurable disturbance, or an unmeasurable disturbance which could only be noticed via its influence on the system's output. Other than that, inputs are variables which could be controlled. On the other hand, a dynamical system is a system which consists of time-domain variables and output. Therefore, the system is dependent on previous values of output, and not dependent on variables (Ljung, 1987).

2.2.3 Definition of System Identification

A model could be developed through experimental data and variables by observing under specific duration using proven method to obtain data which suits the description of the mathematical model, whereby input-output of the system could be distinguished (Bittanti, 2019). The black-box model is a mathematical model which provides only logical definition of its input-output relationship, whereas the white-box model is classical model defined by the knowledge of physics and mathematical laws. Models tend to contain uncertain and unknown parameters and variables. Therefore, parameter could be estimated via experimentation analysis on the behaviour of the system under specific condition. Thus, system identification problems estimate unmeasurable variables from data of observed variables. The science term of identification refers to the designation of model based on experimentation groundworks.

2.2.4 Purpose of System Identification

Traditionally, mathematical models are acquired by describing input and output using applicable mathematical laws which are complicated and time consuming. Mathematical model obtained through this method may consists numerous complex equations, making it unpractical in real life. Accuracy of model may not be achieved mathematically as relationship between variables might not be reliable due to their unknown values, or analytic description. As actual system varies from the mathematical model, connection should not be made between real system with its mathematical description, whereas it is better to compare and relate specific features. Idealisation should dominate implementation as models should be accepted for its practicability. Hence, by using system identification method, the properties of models could be better understood. (Bittanti, 2019).