MODELLING AND ACTIVE VIBRATION CONTROL OF FLEXIBLE MANIPULATOR STRUCTURE

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Specially dedicated to my beloved family
and the blessings from my ancestors

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Nothing come for granted, there must be somebody or something who help us throughout our life.

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ABSTRACT

The purpose of this study is to investigate the application of different system identification techniques such as least square (LS), recursive least square (RLS) and neural network (NN) to identify the system model of a flexible manipulator structure and design a Proportional-Integral-Derivative (PID) controller for the system to control the angular motion and suppress the end-point vibration. The input-output data for the system identification usage is acquired through the experimental setup of a lab scale experimental rig. After the system is identified using the system identification techniques, the result is verifies using mean square error (MSE). All the results are compared which the NN system identification with NAR model has the smallest MSE value of 1.481×10^{-04} and RLS system has the smallest MSE value of 1.690×10^{-04}. The transfer function obtained by using RLS and NN are used to develop the control scheme to suppress the vibration and control the angular motion of the flexible manipulator structure. PID controller is proposed to be used in the flexible manipulator system. The controller was tuned heuristically and automatically in Matlab SIMULINK environment. The results show that the PID controller developed with parametric model is better in suppressing the vibration while the PID controller developed with non-parametric model is better in controlling the angular motion of the flexible manipulator.

ABSTRAK

Penyelidikan ini bertujuan untuk mengkaji penggunaan aplikasi pelbagai kaedah pengenalpastian model sistem seperti kuadrat terkecil (LS), Rekursi Kuadrat Terkecil (RLS) dan Rangkaian Neural (NN) untuk mengenalpasti identiti model struktur rasuk yang fleksibel dan mereka satu sistem pengawal *Proportional-Integral-Derivative* (PID) untuk mengawal gerakan sudut dan menyekat getaran. Data masukan dan keluaran untuk proses pengenalpastian model sistem telah diperolehi melalui eksperimen menggunakan rig ujikaji skala makmal. Selepas sistem tersebut dikenalpastikan mengguna kaedah pengenalpastian model sistem, keputusan telah disahkan dengan menggunakan kaedah Minimum Ralat Kuasa Dua (MSE). Semua keputusan telah dibandingkan dan NN yang digunakan NAR model mempunyai nilai MSE yang terkecil iaitu 1.481×10^{-04} dan RLS mempunyai nilai MSE yang terkecil iaitu 1.690×10^{-04}. Model identiti yang diperolehi digunakan dengan RLS dan NN telah digunakan dalam perekaan sistem kawalan untuk menyekat getaran dan mengawal gerakan sudut pada sistem rasuk fleksibel. Penggunaan pengawalan PID telah dicadangkan. Pengawalan PID akan ditala menggunakan kaedah heuristik dan automatik dalam Matlab SIMULINK. Keputusan telah menunjukkan PID yang direka dalam model yang berparameter berfungsi lebih baik dalam menyekat getaran manakala PID yang direka dalam model bukan parametrik berfungsi lebih baik dalam mengawal gerakan sudut sistem rasuk fleksibel.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANFIS	Adaptive Neuro Fuzzy Inference System
ANN	Artificial Neural Network
ARMA	Autoregressive moving average
ARMAX	Autoregressive moving average model with exogenous input
ARX	Autoregressive External
DA	Distributed-arithmetic
DAQ	Data Acquisition System
FPGA	Field-programmable gate array
GA	Genetic Algorithm
GAPE	Generic Algorithm with Parameter Exchanger
LS	Least Square
MIMO	Multi-input multi-output
MSE	Mean square error
NARMAX	Nonlinear Autoregressive moving average model with exogenous inputs
NARX	Nonlinear Autoregressive External
NN	Neural Network
PDE	Partial Differential Equation
PID	Proportional-Integral-Derivative Controller
PSO	particle swarm optimization
RLS	Recursive Least Square

LIST OF SYMBOLS

n	model order
λ	forgetting factor
w_i	gain factor
$F(v)$	Activation function
K_p	Proportional gain
K_i	Integral gain
K_D	Derivative gain

CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

Automation is an essential part in industrial, thus, a manipulator is used extensively in order to achieve this. Basically, there are two types of manipulator, rigid and flexible manipulator. Theoretically, a rigid manipulator has one fundamental frequency of vibration at an infinite value with finite number of degrees of freedom while a flexible manipulator has many fundamental frequencies of vibration at finite values with infinite number of degrees of freedom (Gao, Wang & Xiao, 2012). Due to the flexibility of flexible manipulator, it is harder to control and operate it. However, as flexible manipulator is more efficient and safer to operate because of its lightness, good damping ration and less pronounced interconnections between different segments of multiple arm links (Gao, Wang & Xiao, 2012), flexible manipulator is more desirable to be used. Therefore, this paper is focus on modelling and active vibration control of flexible manipulator structure manipulator in order to enhance its functionality.

Using flexible manipulators in automation started in early 1980s (Gao, Wang & Xiao, 2012). The earlier studies of manipulators were focused on dynamic modelling of flexible manipulators while the current research is focus on its controllers and implementation on different platforms (Chang, Spowage & Chan, 2014). Researches of flexible manipulators have been done a lot in the area of robotic, aerospace and manufacture. There are several classical ways to model the manipulators such as system identification, finite different method and finite element method. The flexible manipulators can be a flexible beam, two-link manipulator and multiple-link of manipulators, different controller might be used for different style of manipulator. The controller used before such as PID controller, feed-back controller and feed-forward controller.

A high-performance flexible manipulator can be very crucial in certain area which cannot tolerate with single mistake that might occur by it. Thus, it is very challenging in getting high-performance flexible manipulators; several issues need to be resolving including, control and model the flexible structure, control the end-point vibration and possibly some unknown circumstances that might happen within the flexible manipulators. There has been a lot of research been done on it but there is still lacking a perfect resolution.

1.2 Statement of the Problem

Manipulator is used in various applications, thus, the modelling of the flexible manipulators is a very essential part in order to understand and analyse its behaviour. Besides, at the tip of the flexible link of flexible manipulators are having high degrees of freedom which cause unwanted flexural vibrations during movement especially when it is moving at a high speed.

Vibration is a dynamic characteristic that always creates problem or damages in a lot of instruments. To a flexible manipulator, vibration is undesirable as well. Thus, in this study, system identification techniques will be used to model the flexible manipulators in order to explore its dynamic behaviour and gives helpful information on active vibration control of flexible manipulators.

PID controller is having a simple structure, stable and sufficient ability in solving a lot of control problems which letting it to be the most widely used controller in the industry. Thus, PID controller will be the core controller considered in this study to develop the active vibration controller to control the angular motion and conquer the end-point vibration of the flexible manipulator.

Lastly, after finishing the modelling and active vibration control design and analysis of the flexible manipulator, the performance of the controller should be able to be validated and verifies under simulation and experimental method.

1.3 Objectives of the Study

The objectives of this study are

1. To model the dynamic behaviour of a segmented flexible manipulator system under forced vibration via system identification techniques
2. To design and develop active vibration controller for angular motion and end point vibration of the flexible manipulator.
3. To assess, validate and compare the performance of all the models and controller thus developed within simulation and experimental environment.

1.4 Scope of the Study

1. Input-output data acquisition of flexible manipulator under force vibration using lab scale experimental rig.
2. Modelling of the dynamic behaviour of a flexible manipulator using system identification techniques via least square, recursive least square and neural network.
3. Development of an active vibration controller to control the angular motion and to suppress the end-point vibration of the flexible manipulator using PID controller which tuned heuristically and auto tuned system.
4. Validation and verification of performance of all the controllers within simulation environment.

1.5 Research Approach

There are two part of this research, modelling and active vibration control of a flexible manipulator. For the modelling part, data acquisition is carried out to develop the mathematical model of the flexible manipulator using system identification by least square(LS) and recursive least square(RLS) algorithm for linear model estimation. For the nonlinear model, neural network (NN) will be utilized. Transfer function will be obtained to model the flexible manipulator.

After modelling, an active vibration controller is designed, preferably PID controller, to control the angular motion and to suppress the end point vibration of the flexible manipulator. Lastly the model is validated and verified.

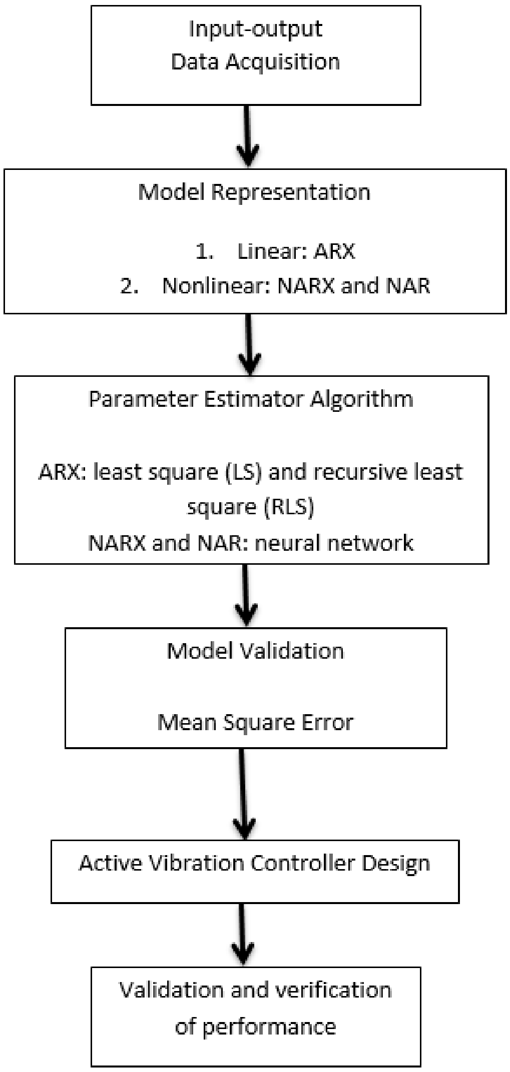

Figure 1.1 Research Approach

1.6 Outline of Thesis

This research is reported into five chapters.

Chapter 1 is the introduction of this research which includes the background, objectives, problem statement, scope of study, research approach of the study and outline of this thesis.

Chapter 2 reviews the previous researches and studies related to flexible manipulators such as its application, how to model it and controller used by flexible manipulator.

Chapter 3 describes the research methodology used in this research which includes the process from input-output data acquisition, system identification by using LS, RLS and NN, validation process and PID controller design.

Chapter 4 focuses on the result of modelling and controller designed obtained by system identification and Simulink environment. This chapter explains the result and validation method of the result. Besides, the models of the flexible beam which is the mathematical description obtained from system identification are discussed. The accuracy of result which obtained by mean square error and correlation tests validation is also discussed in this section. Later on, this chapter discussed on the PID controller design.

Chapter 5 concludes the result and discussion and presents the recommendation based on the result and discussion.

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