INTELLIGENT MODELLING AND ACTIVE VIBRATION CONTROL OF FLEXIBLE MANIPULATOR

MOHSEN GOL ZARDIAN

A project report submitted in partial fulfilment of the
requirement of the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JUNE 2014

Specially dedicated to my mother, my father, my brother and my Bo

For your everlasting love and care…

ACKNOWLEDGEMENT

In preparing this report, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts.

In particular, I wish to express my sincere appreciation to my thesis supervisor, Assoc. Prof. Dr. Intan Zaurah Mat Darus, for encouragement, guidance, critics and friendship. Without her continued support and interest, this thesis would not have been the same as presented here. Her enthusiasm has been a great source of inspiration to me and it is indeed fortunate to be under her supervision and guidance. Her dedication will always be remembered.

I am indeed thankful to those who have shown their full support to the making of this dissertation especially my family members, my mother, my father, my brother and my compassionate friend Liu Linbo. Thank you for all the support and love you gave to me.

ABSTRACT

The purpose of this study is to investigate the application of Least Square (LS), Recursive Least Square (RLS), and Neural Network to estimate the identification of flexible beam structure and development a (Proportional-Integral-Derivative) PID controller for the system. The input and output data used for system identification process were obtained from experimental setup. The performance of system identification used, Lest Squares (LS), Recursive Least Squares (RLS), and Neural Network (NN) were verified using Mean Square Error (MSE) technique. Comparative assessment was conducted to compare all the result obtained and the best transfer function was obtained from RLS system identification approach with smallest MSE value of 8.182×10^{-08}. The transfer function has been used to help the development of control system to suppress unwanted vibration of the flexible manipulator system. In this study, a PID controller has been proposed to use for the vibration suppression. This controller was tuned by using heuristic tuning in Matlab SIMULINK simulation environment.

ABSTRAK

Penyelidikan ini bertujuan untuk mengkaji penggunaan aplikasi kaedah Kuadrat Terkecil (LS), Rekursi Kuadrat Terkecil (RLS), dan Rangkaian Neural (NN) untuk mengenalpasti identiti model struktur rasuk yang fleksibel dan mencadangkan satu sistem pengawalan (Proportional-Integral-Derivative) PID untuk sistem fleksibel tersebut. Eksperimen telah dijalankan untuk memperolehi data masukan dan keluaran yang digunakan dalam proses pengenalpastian model sistem tersebut. Keupayaan LS, RLS, dan NN disahkan dengan menggunakan kaedah Minimum Ralat Kuasa Dua (MSE). Perbandingan telah dijalankan untuk menilai prestasi kaedah-kaedah yang digunakan untuk mencari identiti struktur fleksibel yang terbaik dengan nilai MSE yang terkecil ialah 8.182×10^{-08}diperolehi menggunakan kaedah RLS. Model identiti yang terbaik digunakan dalam perekaan sistem kawalan untuk menyekat getaran yang tidak diperlukan pada sistem manipulator fleksibel. Dalam kajian ini, pengawalan PID telah dicadangkan untuk tujuan menyekat getaran tersebut. Pengawal PID tersebut telah ditala menggunakan kaedah heuristik dan disimulasi menggunakan Matlab SIMULINK.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

4.1 Background of Study

Manipulators are one of the prominent components of robots system. Due to having some functional characteristics, manipulators have been implemented in the industry (Minh et al., 2012; Jnifene, 2007) aero investigations (Hu, 2008; Zarafshan, 2013), biomedical application (Kenser and Howe, 2011; Yaran et al., 2012), and many scientific purposes. When the human cannot afford to carry out some tedious and accurate tasks, automaton's manipulators come in handy to implement such operations; also they have been implored in order to do backbreaking labors in the industry (Ding et al., 2014). In the most of cases flexible manipulator has been preferred rather than its rigid counterpart. Some striking characteristics such as light weight, small size, fast response and consuming low energy encourage using flexible manipulators.

Flexible structure can be referred to the ability of the lightweight structure in the various and complicated applications. The usual flexible structures such as beam, plate, shell, and frame have been used wieldy in engineering applications.

In the industrial application the flexible structure can be used in order to remove the large space of working place that have been occupied with heavy and huge rigid structures. Producing high performance such as the using the less energy to lunch and manoeuvre the flexible structure is another superior attribute of flexible structure.

Kesner, Member, Howe, & Member, The flexible robot manipulator is one of the sensitive flexible structures that has been used for carrying out the acute and precise scientific tasks, like surgical operation and assembling the tiny electronic products (Kesner, Member, Howe, & Member, 2011).

The worldwide usage and increasing demand of robot in scientific applications, many researchers have focused on designing and controlling the precise robot for implementing the any rigorous task, similarly, modelling of flexible manipulator as inherent part of robot control system is considered as well.

Despite the functional attribute of flexible manipulator, there is no guarantee on perfect performance of it. Flexibility in terms of low stiffness characteristic (Qiu and Zhao, 2012; Yatim et al, 2012) result in unwanted vibration or chaotic motion, so the quality of operation could be affected by such vibration. Consequently, Extra oscillation at the operation point leads to time delay and may mess up all the performances. With regard to all consideration, the flexible manipulator has prevalent usage as well, in other word, there have been many superior ways to get over some drawbacks and preserve the applying of the flexible manipulator in the today's application.

Undesirable vibration of robot manipulator when the accuracy is the first and vital factor is not negligible. This unwanted vibration may make the catastrophic incident for human and causes economic losses thus, controlling and supressing such vibration is one of the engineering obsession.

All the prominent consideration related to the vibration control of the flexible robot manipulator call for this study. This vibration is much severe in slender flexible manipulator especially in the tip with or without the external loading.

Yurkovich et al.(1990) stated, there is close relationship between accurate modelling and precise controlling the flexible beam. The key point is flexible structures are suffering from low stiffness that comes from the inherent lightweight properties (Yurkovich, Tzes, & Hillsley, 1990).

Gu et al. (1997) Vibration damping of flexible structure requires obtaining the dynamic behaviour of flexible structure(Gu, Song, & Zhou, 1997), in other word, the proper modelling of motion that express the relationship between inputs and out puts is necessary to design the efficient controller in order to mitigate the unwanted vibration.

During the past years, many rigorous studies have been done in order to drive the mathematical modelling of flexible structure. These researches have been done by considering some additional condition and some simplification due to the complex physical characteristics such as nonlinearities and uncertainties.

Extracting the mathematical model of flexible manipulator by applying the new method in place of classical method would improve the appropriate modelling for designing the adaptive controller strategy. System identification is one of the novel and well-known technique that is established to introduce the transfer function of flexible manipulator motion with making the relationship between the inputs and outputs data in a simple algebraic mathematic form.

1.1 Objectives

The objective of this study is to suppress the vibration of flexible manipulator. Briefly:

1. To present the dynamic modelling of flexible manipulator by using parametric and non-parametric system identification techniques.
2. To investigate the best model from the proposed techniques.
3. To develop the adaptive and robust PID controller to suppress the vibration of flexible manipulator.

1.2 Problem Statement

Numerous application of flexible manipulator has being increased during these days because of striking characteristic of flexibility; however, the flexibility associated with low stiffness results in some problem such as unwanted vibration.

Vibration is one of the dynamic characteristic of any system that related to the any loading or instantaneous stimulations with external factors. Some vibration manifestation is desirable such as vibrating guitar string producing the music, on the other hand, some vibration phenomenon are destructive like the vibrating the suspension bridge in presence of the wind as external excitation.

Manifestation of vibration in the some structure in the inherent fact that may cause the catastrophic loss either in human or economic vision in the excessive vibration cases beside the designing and controlling the vibrating system the maintenance and monitoring such system has priority.

In order to control the vibration such as flexible manipulator as vibrating system, the behaviour of the manipulator must be investigated by modelling the dynamic motion and finding the mathematical model of motion, so the appropriate method should be introduced except for the classical approach.

The novel and adaptive method of modelling is called system identification that based on subset data as inputs and outputs, the inputs data are include the discretized input signal, in other word, excitation signal and output data are include the response of input or oscillating motion as discretized signal. The outcome of system identification modelling is the transfer function of model that has been presented as difference equation in which indicates the relationship between output and inputs.

With respect to system identification approach there are divers methods to describe the system identification, some researcher have proposed different models structure that used the system identification method to describe the inputs and outputs data. There are two main prominent standpoints with regard to system identification, one is linear model structure and another is nonlinear model structure. In the some literature is known as parametric and nonparametric model respectively.

This study has used two method of system identification. First of all implementing the linear model structure using ARX model and estimation of proposed model is done by least square (LS) and recursive least square (RLS) as parametric model estimation. The proposed model is in form of difference equation to show the mathematical model. The second proposed model is nonlinear model structure, in this approach the neural network (NN) concept is employed to present the model structure. The resulting outcome of neural network is considered as nonlinear modelling that relates the inputs and outputs of system.

1.3 Scope of Study

1. Experimental test rig of flexible manipulator is used to obtain the inputs and outputs. (data set).
2. Establishment of linear and nonlinear dynamic model.
3. Using least square (LS) and recursive least square (RLS) for estimation of linear model and neural network (NN) approach as nonlinear model estimation.
4. Developing the PID controller to supress the vibration of flexible manipulator.

1.4 Research Approach

This study is divided into two prominent parts, first of all the mathematical model which is extracted by using the system identification approach, namely least

square (LS) and recursive least square (RLS) as linear model estimation, then the neural network (NN) technique has been applied in order to find the nonlinear model estimation. Both proposed model present the transfer function of model. Finally, the proposed modelling is used to design the PID controller in order to supress the vibration of flexible manipulator. The flow chart of this research is illustrated in Figure 1.1.

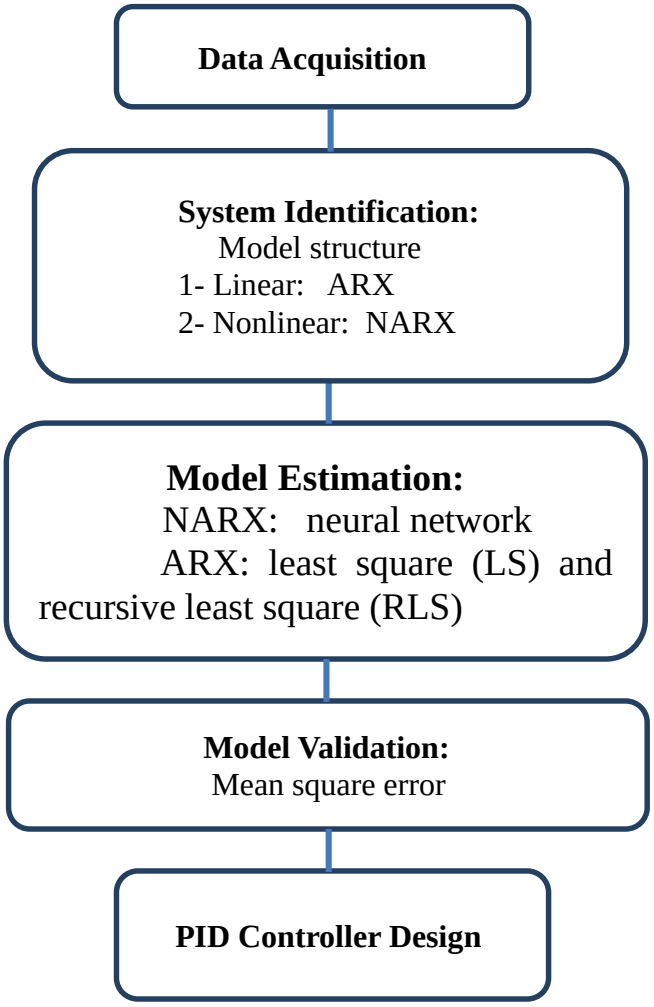

Figure 1.1 Research Approach

1.5 Outline of Thesis

This research is divided into five main chapters as below:

Chapter 1 presents the introduction, background, and study of the flexible manipulator, the objective, problem statement, scope and theoretical framework of this study.

Chapter 2 includes review of study the previous research and study of other researchers in modelling of flexible manipulator.

Chapter 3 presents the research methodology of this study, the procedure of implementation of research, include of gathering data, system identification using least square, recursive least square and neural network, validation test and controller design is proposed.

Chapter 4 concentrates on obtained result from system identification and correctness and accuracy of result from LS, RLS and NN using the least square error and also develop the mathematical model in order to designing and tuning the controller .

Chapter 5 contains the conclusion part and recommendation based on results and discussion.

REFERENCES

Ã, F. R., & Feliu, V. (2008). ARTICLE IN PRESS New online payload identification for flexible robots . Application to adaptive control, *315*, 34–57. doi:10.1016/j.jsv.2008.02.003

Ã, G. N., & Tzes, A. (2010). Application of adaptive lattice filters for modal parameter tracking of a single flexible link carrying a shifting payload. *Mechanical Systems & Signal Processing*, *24*(5), 1338–1348. doi:10.1016/j.ymssp.2009.11.007

Ã, S. E. S., & Abdullah, O. (2008). ARTICLE IN PRESS An event-based vibration control for a two-link flexible robotic arm : Numerical and experimental observations, *313*, 375–394. doi:10.1016/j.jsv.2006.09.021

Ã, Y. T., Ãã, F. S., & Sun, Z. (2006). Neural network control of flexible-link manipulators using sliding mode, *70*, 288–295. doi:10.1016/j.neucom.2006.01.030

Ahmad, M. A., Ismail, R. M. T. R., & Ramli, M. S. (2010). Control Strategy for Active Vibration Suppression of Flexible Robot Manipulator, 741–746.

Becedas, J., & Trapero, J. R. (2007). Fast identification method to control a flexible manipulator with parameter uncertainties, (April), 10–14.

Boulevard, T., & Lane, L. (1994). An Iterative Scheme for Learning Gravity Compensation in Flexible Robot Arms * t, *30*(6).

Chatterjee, A., & Chatterjee, R. (2007). Neuro-fuzzy state modeling of flexible robotic arm employing dynamically varying cognitive and social component based PSO, *40*, 628–643. doi:10.1016/j.measurement.2006.09.004

Cole, M. O. T., Wongratanaphisan, T., Pongvuthithum, R., & Fakkaew, W. (2008). Automatica, *44*(11), 2876–2883. doi:10.1016/j.automatica.2008.03.022

Conference, I. (2011). No Title, *0*.

Feliu, V., Castillo, F. J., Ramos, F., & Somolinos, J. A. (2012). Mechatronics Robust tip trajectory tracking of a very lightweight single-link flexible arm in

presence of large payload changes. *Mechatronics*, *22*(5), 594–613. doi:10.1016/j.mechatronics.2012.01.012

Feliu, V., Pereira, E., & Roncero, P. (2006). Feedforward control of multimode single-link flexible manipulators based on an optimal mechanical design, *54*, 651–666. doi:10.1016/j.robot.2006.02.012

Gu, G., Song, H., & Zhou, K. (1997). An Integrated Approach to Modeling and Control of Flexible Structures via, *50*(December), 0–5.

Hassan, M., Dubay, R., Li, C., & Wang, R. (2007). Active vibration control of a flexible one-link manipulator using a multivariable predictive controller, *17*, 311–323. doi:10.1016/j.mechatronics.2007.02.004

Jen, C. W., Johnson, D. A., & Gorez, R. (1996). A reduced-order dynamic model for end-effector position control of a flexible robot arm, *4*.

Kesner, S. B., Member, S., Howe, R. D., & Member, S. (2011). Force Control of Flexible Catheter Robots for Beating Heart Surgery, 1589–1594.

Miro, J. V, & White, A. S. (2002). Modelling an industrial manipulator a case study, *9*, 293–319.

Montazeri, A., Poshtan, J., & Choobdar, A. (2009). Performance and robust stability trade-off in minimax LQG control of vibrations in flexible structures. *Engineering Structures*, *31*(10), 2407–2413. doi:10.1016/j.engstruct.2009.05.011

Mosayebi, M., Ghayour, M., & Sadigh, M. J. (2012). A nonlinear high gain observer based input – output control of flexible link manipulator. *Mechanics Research Communications*, *45*, 34–41. doi:10.1016/j.mechrescom.2012.06.004

Polytechnic, Y. (n.d.). Dynamic Ana (y . sis of a Two-link Flexible Manipulator System using Extended Bond Graphs, 1113–1134.

Pradhan, S. K. (n.d.). NARMAX Modeling of a Two-Link Flexible Robot, (3), 1–5.

Qian, W. T., & Ma, C. C. H. (1991). Experiments on a flexible one-link manipulator, 262–265.

Qiu, Z. (2012). Adaptive nonlinear vibration control of a Cartesian flexible manipulator driven by a ballscrew mechanism. *Mechanical Systems and Signal Processing*, *30*, 248–266. doi:10.1016/j.ymssp.2012.01.002

Tian, L., & Collins, C. (2005). Adaptive neuro-fuzzy control of a flexible manipulator, *15*, 1305–1320. doi:10.1016/j.mechatronics.2005.02.001

Vakil, M., Fotouhi, R., & Nikiforuk, P. N. (2009). Mechatronics Causal end-effector inversion of a flexible link manipulator. *Mechatronics*, *19*(7), 1197–1210. doi:10.1016/j.mechatronics.2009.03.010

Yatim, H., Darus, I. Z. M., & Hadi, M. S. (2013). Particle Swarm Optimization for Identification of a Flexible Manipulator System, (1), 112–117.

Yatim, H. M., Darus, I. Z. M., & Hadi, M. S. (2013). Modeling of Flexible Manipulator Structure Using Genetic Algorithm with Parameter Exchanger, 37–42. doi:10.1109/CIMSim.2013.15

Yurkovich, S. (1990). Experiments in Identification and Control of Flexible-Link Manipulators, (February).

Yurkovich, S., Tzes, A. P., & Hillsley, K. L. (1990). Control and system identification of a, 1626–1631.

Ziaei, K., & Ã, D. W. L. W. (2006). Application of orthonormal basis functions for identification of flexible-link manipulators, *14*, 99–106. doi:10.1016/j.conengprac.2004.11.020

Ziaei, K., Ni, L., & Wang, D. W. L. (2009). Control Engineering Practice QFT-based design of force and contact transition controllers for a flexible link manipulator, *17*, 329–344. doi:10.1016/j.conengprac.2008.06.004

Qiu, Z. & Zhao, Z., 2012. Pneumatic Drive Active Vibration Control for Flexible Manipulator Using an Adaptive Interactive PD Controller. , pp.1956–1961.

Reis, C.P., 2012. Motion planning and actuator specialization in the control of active-flexible link robots. , 331, pp.3255–3270.

Rigatos, G.G., 2009. Model-based and model-free control of flexible-link robots : A comparison between representative methods. Applied Mathematical Modelling, 33(10), pp.3906–3925. Available at: http://dx.doi.org/10.1016/j.apm.2009.01.012.

Rocha, C.R.Ã., Tonetto, C.P. & Dias, A., 2011. Robotics and Computer-Integrated Manufacturing A comparison between the Denavit – Hartenberg and the screw-based methods used in kinematic modeling of robot manipulators $. Robotics and Computer Integrated Manufacturing, 27(4), pp.723–728. Available at: http://dx.doi.org/10.1016/j.rcim.2010.12.009.

Payo, I., Feliu, V. & Cortázar, O.D., 2009. Force control of a very lightweight single-link flexible arm based on coupling torque feedback. *Mechatronics*, 19(3), pp.334–347. Available at:

http://linkinghub.elsevier.com/retrieve/pii/S0957415808001748 [Accessed May 9, 2014].

Pereira, E. et al., 2011. Integral Resonant Control for Vibration Damping and Precise Tip-Positioning of a Single-Link Flexible Manipulator. , 16(2), pp.232–240.

Pradhan, S.K., NARMAX Modeling of a Two-Link Flexible Robot. , (3), pp.1–5.

Franke, R. et al., 2009. Vibration control of a multi-link Àexible robot arm with Fiber-Bragg-Grating sensors. , pp.3365–3370.

Gautier, M. et al., 2013. Dynamic Identification of flexible joint manipulators with an efficient closed loop output error method based on motor torque output data. , pp.2949–2955.

Gurses, K., Buckham, B.J. & Park, E.J., 2009. Vibration control of a single-link flexible manipulator using an array of fiber optic curvature sensors and PZT actuators. *Mechatronics*, 19(2), pp.167–177. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0957415808001438 [Accessed May 9, 2014].

Malzahn, J. et al., 2010. Input shaping and strain gauge feedback vibration control of an elastic robotic arm. , pp.672–677.

Mansour, T. et al., 2008. Experimental Verification on Vibration Suppression of a Flexible Manipulator Using MPID Controller. , pp.2896–2901.

Merc, G., Lovera, M. & Laroche, E., 2011. Identification of a flexible robot manipulator using a linear parameter-varying descriptor state-space structure. , pp.3–8.

Mirzaee, E., Eghtesad, M. & Fazelzadeh, S. a., 2010. Maneuver control and active vibration suppression of a two-link flexible arm using a hybrid variable structure/Lyapunov control design. *Acta Astronautica*, 67(9-10), pp.1218–1232. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0094576510002456 [Accessed May 9, 2014].

Montazeri, A., Poshtan, J. & Choobdar, A., 2009. Performance and robust stability trade-off in minimax LQG control of vibrations in flexible structures. *Engineering Structures*, 31(10), pp.2407–2413. Available at: http://dx.doi.org/10.1016/j.engstruct.2009.05.011.

Morales, R., Feliu, V. & Jaramillo, V., 2012. Position control of very lightweight single-link flexible arms with large payload variations by using disturbance

observers. *Robotics and Autonomous Systems*, 60(4), pp.532–547. Available at: http://dx.doi.org/10.1016/j.robot.2011.11.016.

Moreno-valenzuela, J. & González-hernández, L., 2011. Operational space trajectory tracking control of robot manipulators endowed with a primary controller of synthetic joint velocity ☆. *ISA Transactions*, 50(1), pp.131–140. Available at: http://dx.doi.org/10.1016/j.isatra.2010.08.002.