HYBRID LEARNING CONTROL SCHEMES WITH INPUT SHAPING OF A FLEXIBLE MANIPULATOR SYSTEM

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Dedicated to my family especially my parents, sister, brothers, and all of my friends.

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ABSTRACT

Input shaping is a simple method for reducing the residual vibration in positioning lightly damped systems. Although several input shaping techniques have been derived to control a flexible manipulator system without payload, theoretical results are hard to be traced for their application to control a flexible manipulator system in real time. This project attempts to describe a practical approach to investigate and develop a hybrid iterative learning control scheme with input shaping. An experimental flexible manipulator rig and corresponding simulation environment are used to demonstrate the effectiveness of the proposed control strategy. In this work, a single link flexible robot manipulator that moves in horizontal plane is considered. A collocated proportional-integral-derivative (PID) controller utilizing hub-angle and hub-velocity feedback is developed for control of rigid-body motion of the system. This is then extended to control the system with acceleration feedback for optimization of the learning parameters and a feed forward controller based for nonlinear model closed loop system on input shaping technique for control of vibration (flexible motion) of the system. The system performance with the controllers is presented and analysed in simulation using MATLAB and SIMULINK. The performance of the PID controller with input shaping is assessed in terms of level of vibration reduction. The effectiveness of the control schemes in handling various speed of flexible link is also analyzed. The performance of the system in term of with and without input shaping method also been compared. From the simulation results, satisfactory vibration reduction of a flexible manipulator has been achieved using the proposed method.

ABSTRAK

Pembentukan input adalah satu kaedah mudah untuk mengurangkan getaran sisa dalam kedudukan sistem teredam ringan. Walaupun beberapa pembentukan input teknik telah dirumuskan untuk mengawal sistem manipulator fleksibel tanpa muatan, secara teorinya keputusan untuk aplikasi adalah sukar untuk dikenal pasti dan diperolehi untuk mengawal sistem manipulator fleksibel dalam model sebenar. Projek ini cuba untuk menerangkan pendekatan yang praktikal untuk menyiasat dan membangunkan skim hibrid kawalan pembelajaran iteratif dengan pembentukan input. Satu eksperimental manipulator fleksibel dan persekitaran simulasi yang sepadan digunakan untuk menunjukkan kebersanan strategi kawalan yang dicadangkan. Dalam kajian ini, fleksibel robot manipulator yang bergerak dalam satah mengufuk dipertimbangkan. Satu pengawal *'collocated proportional-integral-derivative (PID)'* menggunakan maklum balas *'hub-angle'* dan *'hub-velocity'* dibangunkan untuk mengawal pergerakan jasad tegar system ini. Ini kemudiannya dilanjutkan untuk menggabungkan kawalan pembelajaran iteratif dengan maklum balas pecutan untuk pengoptimuman parameter pembelajaran dan pengawal *'feedforward'* untuk model *'nonlinear'* sistem *'closed loop'* berdasarkan teknik pembentukan input untuk mengawal getaran sistem (gerakan fleksibel). Prestasi sistem dengan pengawal dikemukakan dan dianalisis dalam simulasi menggunakan MATLAB dan SIMULINK. Prestasi pengawal *'PID'* dengan pembentukan input dinilai dari segi tahap pengurangan getaran. Keberkesanan skim kawalan dalam mengendalikan pelbagai kelajuan juga dianalisis. Prestasi sistem dengan pembentukan input dan tanpa pembentukan input juga telah dibandingkan. Dari keputusan simulasi didapati pengurangan kadar getaran yang memuaskan telah diperolehi menggunakan teknik yang diperkenalkan.

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ABBREVIATIONS

PID	-	Proportional-Integral-Derivative
ILC	-	Iterative Learning Control
PhD	-	Doctor of Philosophy
K_p	-	Proportional Gains
K_i	-	Integral Gains
K_v	-	Derivative Gains
θ	-	Hub Angle
$\dot{\theta}$	-	Hub velocity
A_c	-	Motor Amplifier Gain
ξ	-	Damping ratio
ω_n	-	Natural frequency
NI	-	National Instrument
DC	-	Direct Current
AC	-	Alternating Current
DAQ	-	Data Acquisition Board
ADC	-	Analog to Digital Converter
CPU	-	Central Processing Unit
IC	-	Integrated circuit
PCB	-	Printed Circuit Board
PCI	-	Peripheral Component Interconnect
SISO	-	Single Input Single Output
MIMO	-	Multiple Input Multiple Output
OS	-	Over Shoot
RTW	-	Real Time Workshop
RTWT	-	Real Time Windows Target

CHAPTER I

INTRODUCTION

1.1 Project Introduction

Robot manipulators are widely used in space and industrial applications. Nowadays, robotic manipulators can be used for completing the complex tasks such as assembling and working for unmanned places. Traditional robot manipulators have been built and design with the high structural stiffness by using heavy and bulky materials; hence some drawbacks such as low motion speed, high power consumption, high capacity actuators and high manufacturing cost may appear. These problems occur due to the condition where the robot manipulators are usually heavy with respect to their payloads.

Flexible manipulator system is an important element in today's manufacturing and assembly industry. It is capable of performing many different tasks and operations precisely without requiring common safety and comforts the human need. Flexible manipulator systems are driven by computers. Their motions are controlled by a controller that is under the supervision of the computer.

Flexible robotic manipulators are known by its advantages over conventional rigid robotic arms; they require less material, are lighter in weight, have higher manipulation speed, lower power consumption, require smaller actuators, are more manoeuvrable and transportable, are safer to operate due to reduced inertia, have enhanced back-drive ability due to elimination of gearing, have less overall cost and higher payload to robot weight ratio [1]. These advantages lead to the usage of flexible manipulators for many complex and dangerous applications that include in space exploration and hazardous environments.

However, the control of flexible manipulators to maintain accurate positioning is an extremely challenging problem. Due to the flexible nature and distributed characteristics of the system, the dynamics are highly non-linear and complex. Problems arise due to precise positioning requirement, vibration due to system flexibility, difficulty in obtaining accurate model of the system and non-minimum phase characteristics [2, 3]. There exists a residual vibration in flexible robot manipulators systems, in which the end effect or keeps vibrating even though nominal motion is already completed.

The actual goal in the flexible manipulator modelling system is to achieve a model that can represent the actual system behaviour. In this respect, a control mechanism that accounts for both the rigid body and flexural motions of the system is required in order to maintain the end-point positional accuracy. If the advantages associated with lightness are not to be sacrificed, accurate models and efficient controller for flexible robot manipulators have to be developed.

The control strategies for flexible manipulator systems can be divided into feedforward and feedback control. In order to reduce end-point vibration, the traditional closed-loop feedback can be used. The closed-loop system will then benefit from the inherent advantages of feedback, such as noise attenuation, disturbance rejection and insensitivity to parameter variations. Nevertheless, the feedback system can be difficult to implement in practice because it requires reliable sensor information for feedback, which is not be so easily available. Another method is input shaping, that is a feedforward technique used to reduce residual vibration of the system, where the input is typically convolved with a sequence of impulses (an input shaper) to yield a shaped input. These methods are popular in industry because they are relatively simple to implement the preshaped input together with closed-loop feedback strategies to receive the benefits of both systems.

1.2 Objectives

This project attempts to design a controller by using hybrid learning control scheme with input shaping for flexible manipulator system that can move as robustness, quickly, accurately and safely as possible without residual vibration during the operation. The simulation of the dynamic model will be performed by using MATLAB and SIMULINK.

1.3 Problem Statement

The residual vibration that occur in the flexible manipulator system during the operation interfere the performance of the manipulator. Flexible robot structures vibration problems when commanded to perform rapid motion. These vibrations are not important and can be ignored if it operates at low speed. However, in moderate high speed system these vibrations become larger and important. At this condition, because various parts of the structure no longer move the way they were intended to move and the system performance will be affected when vibration occurs during the movement of a flexible manipulator. This is a serious problem especially for the application that needs high accuracy. Moreover, the behaviour of the system is significantly affected by payload variations.

The performance of the input shaping technique in modelling the flexible manipulators has been previously investigated. These investigations show that this technique can be used to obtain a good representation of the system. It has been proved that input shaping is sufficient to reduce or eliminate the residual vibration of a flexible manipulator. However, the effects of hybrid learning control schemes with input shaping in handling payloads have not been satisfactorily addressed.

1.4 Scopes

While doing the project, the scope of work plays very important role, which is a guidelines for student should attain to fulfil the requirement of the project. This project focuses on:

i. Literature review on the concept flexible manipulator system, input shaping method design and PID algorithm.
ii. Design and build the model of flexible manipulator by using closed-loop system in MATLAB.
iii. Implement the hybrid input shaping method with PID controller into the closed-loop system.
iv. Develop the actual model of a single-link flexible manipulator that moves in a horizontal plane.
v. Integrate between the hardware and the software to using SIMULINK and Real Time Workshop (RTW) in order to get the desired output.

1.5 Methodology

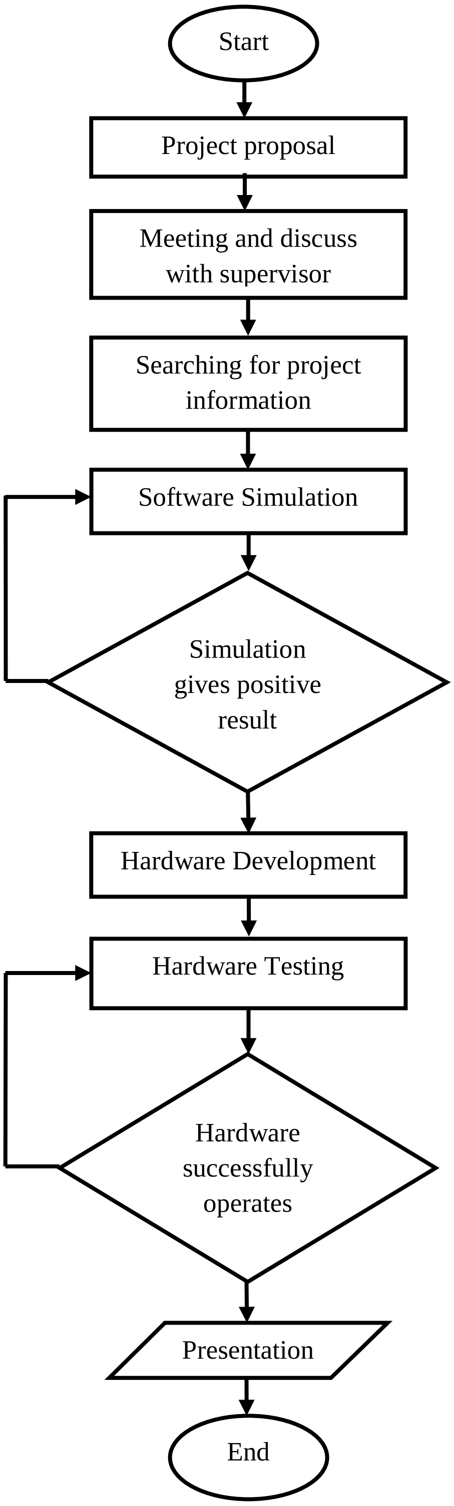

Figure 1.1: Flow Chart of Project Methodology

1.6 Thesis Outline

This thesis consists of five chapters. Chapter I provide some background of the project, the objective and the scope of project. Chapter II contains the literature review on previous researches, several important concepts of input shaping, technology and tools used in the study. Chapter III discusses the research methodology in order to complete this project. Every stages of research methodology are briefly portrayed in flow chart. It also explained the mathematical and simulation tools that used to realize this project. Chapter IV follows with the result and analysis part. This chapter also explains the simulation environment, the initial values of each parameter, the MATLAB simulation and SIMULINK used in simulation part of final derived model of a single-link flexible manipulator. It also includes the simulation results of a single-link flexible manipulator, the analysis of the simulation results and the discussion related to simulation results. Chapter V discusses on the hardware development and analysis. Besides that, this chapter also will discuss detailed about the hardware design contents schematic diagram, wire diagram, products needed, and components required in order to build a flexible manipulator model as prototype in this project. The project is then concluded in Chapter VI with some recommendations and future works.

1.7 Summary of This Chapter

This chapter introduced this project with the advantages of flexible manipulator compared to rigid arm. This chapter also described the objectives and scope of this project. The outline of thesis is discussed in the final part of this chapter.