INPUT SHAPING FOR VIBRATION-FREE POSITIONING OF FLEXIBLE MANIPULATOR SYSTEMS

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To my late father and beloved family

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ABSTRACT

Input shaping is a method for reducing the residual vibration in positioning at the same times to move the systems. For controlling part, a continuous and differentiable function is introduced to define the desired motion and the input is shaped by inverse dynamic analysis. The shaped input function is derived from the specified output function so that the designer can choose the speed and shape of the motion within the limitations of the drive system. The simulation has been done to the spring-mass-damper system which is a second order system to study the application of the technique to the system. Next, the same technique is applied to a flexible manipulator system. In the proposed method the parameters that need to be defined is the position of the hub angle and displacement. Simulated responses of the position of the trolley and sway angle of the mass are presented using MATLAB. The performances of the inverse dynamic analysis are compared with the journal results. From the simulation results, satisfactory vibration reduction of a flexible manipulator system has been achieved using the proposed method.

ABSTRAK

'Input shaping' merupakan kaedah yang di gunakan untuk mengurangkan getaran semasa menggerakkan sesuatu sistem. Pada sistem pengawal, fungsi persamaan berterusan dan boleh beza di gunakan untuk mendapatkan respons yang dikehendaki dan persamaan input diterbitkan menggunakan teknik *'inverse dynamic'.* Setiap penyelesaian matematik yang diperolihi daripada respons output yang dikehendaki supaya pengkaji dapat memilih kelajuan dan bentuk respons yang diperlukan supaya berada dalam had maksima sesuatu sistem. Simulasi dijalankan ke atas sistem spring-beban teredam iaitu sistem order kedua untuk mengkaji kesan teknik ini kepada sistem tersebut. Seterusnya, teknik yang sama diaplikasikan kepada sistem '*Flexible manipulator systems*'. Dengan menggunakan teknik ini, parameter yang akan dikaji adalah kedudukan sudut pusat dan pengalihan sistem. Respons bagi kedudukan troli dan sudut ayunan beban akan ditunjukkan menggunakan perisian MATLAB. Prestasi output menggunakan input *'inverse dynamic'* di paparkan berbanding daripada jurnal sains yang di perolihi. Dari keputusan simulasi didapati pengurangan kadar getaran yang memuaskan telah diperolehi menggunakan teknik yang dikaji.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF APPENDICES

LIST OF SYMBOLS

τ	- Torque
t	- Time
s	- Second
E	- Young Modulus
I	- Area moment of inertia
A	- Cross sectional area
ρ	- Mass density per unit volume
I_h	- Hub inertia
M_n	- Mass matrix
K_n	- Stiffness matrix
N	- Number of element
L	- Length of element
F	- Vector of external force
Q	- Nodal displacement vector
Θ	- Angular displacement
$\dot{x}$	- Velocity
$\ddot{x}$	- Acceleration
$\dot{\theta}$	- Angular Velocity
$\ddot{\theta}$	- Angular Acceleration

CHAPTER 1

INTRODUCTION

1.1 Introduction

Most existing robotic manipulators are designed and built in a manner to maximize stiffness, in an attempt to minimize system vibration and achieve good positional accuracy (Mohamed and Tokhi, 2004). High stiffness is achieved by using heavy material. As a consequence, such robots are usually heavy with respect to the operating payload. This, in turn, limits the operation speed of the robot manipulation, increases the actuator size, and boosts energy consumption and increase the overall cost. Moreover, the payload to robot weight ratio, under such situation, is low. In order to solve these problems, robotic systems are designed to be lightweight and thus posses some level of flexibility. Conversely, flexible robot manipulator exhibits many advantages over their rigid counterparts: they require less material, are lighter in weight; have higher manipulation speed, lower power consumption, require small actuators, are more maneuverable 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 (Book and Majette, 1983).

However, the control of flexible robot manipulators to maintain accurate positioning is an extremely challenging problem. Due to the flexible nature and distributed characteristic of the system, the dynamics are highly non-linear and complex. Problems arise due to precise positioning requirement, vibration due to system flexibility, the difficulty in obtaining accurate model of the system and non minimum phase characteristics of the system (Piedboeuf et al, 1983; Yurkovich, 1992). Therefore, flexible manipulators have not been favored in production industries, as the manipulator is required to have reasonable end-point accuracy in response to input commands. In this respect, a control mechanism that accounts for both rigid body and flexural motions of the system is required. If the advantages associated with lightness are not to be sacrificed, accurate models and efficient controllers have to be developed (Mohamed, Tokhi, 2004).

1.2 Background of the Problems

Control of machines that exhibit flexibility becomes important when designers attempt to push the state of the art with faster and lighter machines. Many researches have examined different controller configurations in order to control machines without exciting resonances. However, after designing a good controller, the input commands to the closed-loop system are 'desired' trajectories that the controller treats as disturbances. Often these 'desired' trajectories are step inputs or trajectories that the machine cannot rigidly follow (Singer and Seering, 1989).

Active vibration control of slewing flexible structures, such as flexible robotic manipulator systems, have experienced rapid growth in recent years. Most of the attention has been focused on eliminating vibrations that result in the structure when control applied (Anthony and Yurkovich, 1993). The vibration of flexible manipulator or system often limits speed and accuracy. The vibration of such manipulator or system is usually caused by changes in the reference command or from external disturbance. If the system dynamics are known, commands can be generated that will cancel the vibration from the system's flexible modes (Bhat and Miu, 1990; Singer, 1989; Singer and Seering, 1990; Smith, 1957). Accurate control of flexible structures is an important and difficult problem and hasbeen an active area of research (Book, 1993; Junkins and Kim, 1993).

1.3 Statement of the Problems

Vibration is a concern of virtually every engineering disciple; mechanical engineers continually face the problem of vibration because mechanical systems vibrate when performance is pushed to the limit. The typical engineering solutions to vibration are to design 'stiff' systems, add damping to flexible system, or develop a good controller. Input shaping is another possibility for vibration control that can supplement methods (Singhose et al., 1990).

Plump et al. (1987) have examined the use of piezoresistive polymer films to generate additional damping in a structure. Albert Thomas et al. (1985) have used a thin layer of viscoelastic material to obtain passive damping that has enhanced system stability. Crawley et al. (1986) have examined the use of a distributed array of piezoelectric device for actuation on a structure. Cannon et al. (1984) have examined feedback control with non collocated end-point position measurements for a single link flexible robot. Hollars et al. (1986) have compared four different control strategies for a two-link robot with elastic drives. Kotnik et al. (1998) have examined feedback acceleration techniques for residual vibration reduction.

An early form of input shaping was the use of posicast control by Smith (1958). This technique breaks a step of certain amplitude into two smaller steps, one which is delayed in time. The result is a reduced settling time for the system. Optimal control approaches have also been used to generate input profiles for commanding vibratory systems. Junkins et al. (1986) and Chun et al. (1985) have also made considerable progress towards practical solutions of the optimal control formulation for flexible systems. Gupta and Narendra (1980), and Junkins et al. (1986) have included some frequency shaping terms in the optimal formulation. Farrenkopf (1979) has developed velocity shaping techniques for flexible spacecraft. Swigert (1980) demonstrated that torque shaping modeling decomposes into second order harmonics oscillators.

Singer and Seering (1989) have shown that residual vibration can be significantly reduced for single mode system by employing an input shaping method that uses a simple system model and requires very little computation. The system model consists only of the system’s natural frequency and damping ratio. Constraints on the system inputs results in zero residual vibration if the system model is exact. When modeling errors occurs, the shaped input function keeps the system vibration at a low level that is acceptable for many applications. Extending the method to multi mode system is straight forward. The shaping method involves convolution of a desired input with sequence of impulses to produce an input function that reduces vibration. Selection of impulse amplitude and time location dictates how well the system performs. Figure 1.1 shows how an impulse sequence can be convolved with system input to generate shaped inputs. Three-impulse sequences have been shown to yield particular effective system inputs both in terms of vibration suppression and response (Singer and Seering, 1989).

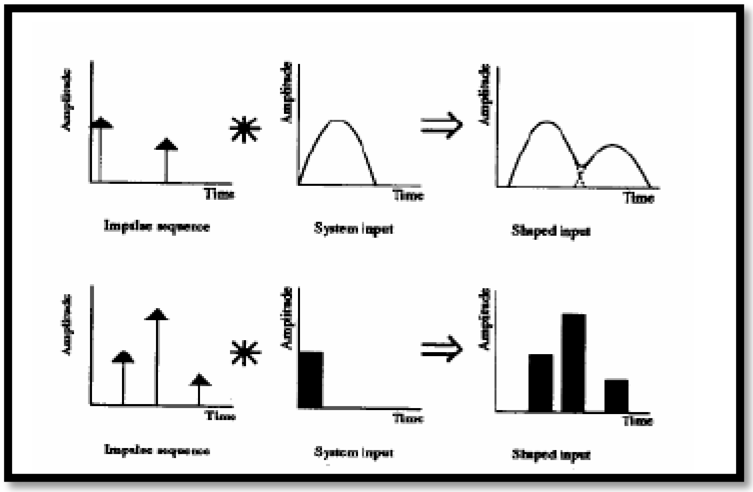


Figure 1.1: Convolution of an impulse sequence with a system input

The shaping method is effective in reducing vibration in both open and closed loop systems. The selection of amplitude and time location of the impulse is very crucial and affects the system. If the parameters do not match the cancellation of the vibration, the system's vibration might be increased. Therefore, optimization of the input shaping is needed to achieve better performance of the flexible manipulator.

1.4 Objective of the Study

(a) To study the dynamic characteristic of the flexible manipulator in order to construct the controlling method to reduce the vibration.

(b) To introduce a new method in determining the optimal input shaping using inverse dynamics.

(c) To study the performance of a new method for vibration control of a flexible robot manipulator.

(d) Design and build the input and flexible manipulator systems used the National Instrument toolbox blocks in the MATLAB to control the system.

Some assumptions and limitations are made along the study to reduce the complexity in solving the problem.

1.5 Scope of Study

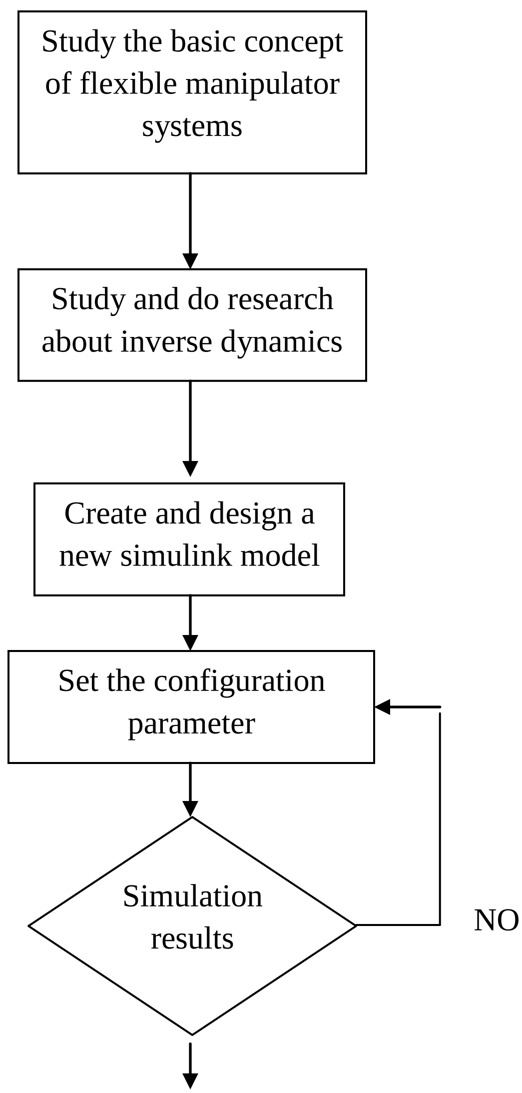
The scope of study is divided into three main parts. The first part is to study the previous research regarding the existing methods in vibration reduction for flexible robot manipulators. The flexible manipulator system considered in this work is a single-link flexible manipulator that moves in a horizontal plane.

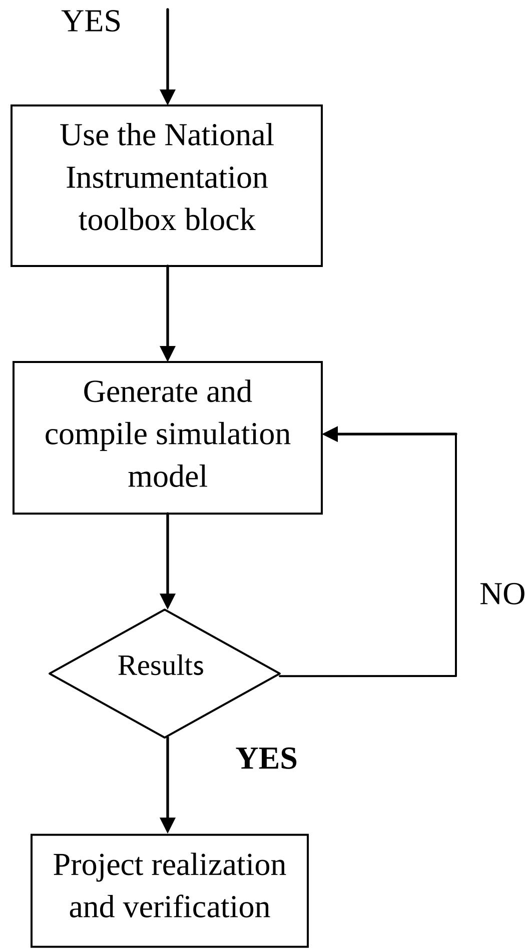
The second part of the project is to study the dynamic characteristics of the flexible manipulator (Martins et al., 2003). The existing dynamic model of the system using inverse dynamics method will be used. The study is done to understand the dynamic behaviors of the flexible manipulator system. This is very an important part of the research in order to design a good controller for the system. The third part of study is to design a suitable input shaper to control the flexible manipulator system. A new approach in designing input shaper methods will be introduced and optimized for reduction in vibration for flexible manipulator system. This work will be carried out through simulation and optimizes the continuity of previous research (Mohamed and Tokhi, 2004).

1.5.1 Significance of Study

An optimal input shaping technique is presented for controlling vibration for flexible manipulator system. Vibration is eliminated by convolving a sequence of impulses, an input shaper, with a desired system command to produce a shaped input. The nature and distributed dynamic characteristics of the flexible manipulator system are highly non-linear and complex is controlled by shaped input. This will ensure the flexible manipulator system to maintain accurate position. The implication of the reduction of vibration in flexible manipulator system using the optimal input shaping enables it to be introduced in space structures, flexible aircraft wings and robotic manipulators (Marc, 1998). Another area of interest is in disk drives, where read/write heads mounted at the end of small but flexible assemblies must be removed rapidly to distant tracks while being subjected to minimum residual vibrations (Miu,1993). Thus, reducing the cost and increasing the production to its advantage.

1.6 Methodology




YES
Use the National Instrumentation toolbox block
Generate and compile simulation model
NO
Results
YES
Project realization and verification

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

One of the present challenges in the reduction of the vibration in the flexible manipulator is the optimization of desired input pattern with minimum vibration. The vibration is a concern of virtually every engineering discipline and mechanical engineers continually face the problem of vibration because mechanical systems vibrate when performance is pushed to the limit. The typical engineering solutions to vibration are to design 'stiff' systems, add damping to flexible system, or develop a good controller. Input shaping is another possibility for vibration control that can supplement methods.

2.2 Review of Input Shaping Method

Input shaping improves response time and positioning accuracy by reducing residual vibrations in computer controlled machines. The method requires only a simple system model consisting of simple estimates of the natural frequencies and damping ratios. Input shaping is implemented by convolving a sequence of impulses, an input shaper, with a desired system command to produce a shaped input that is then used to drive the system.

Several investigations have been conducted on input shaping since its original presentation by Singer and Seering (1989; 1990). A method for increasing the insensitivity to modeling errors has been presented by Singhose et al. (1990). However, the previous studies do not take into account the distributions of the parameter variations. A new input shaping method that allows the range of system parameter values is to be weighed according to the expected modeling errors has been proposed. Comparisons with previously proposed input shaper designs in term of shaper length, frequency insensitivity, and expected level of residual vibration are presented by Lucy et al. (1997). Input shapers can be made very insensitive to parameter uncertainty; however, increasing insensitivity usually increases system delays. A design process that generates input shapers with insensitivity-to-time-delay ratios that are much larger than traditionally designed input shapers is presented (Singhose et al., 1995b). Techniques for designing the impulse sequence for two mode system are presented and compared as a function of mode ratio (Singhose et al., 1997b). Hyde and Seering (1991) have shown the effective input shaping for multiple mode systems.

Mohamed and Tokhi (2003) have presented experimental investigations toward the development of feed-forward control strategies for vibration control of a flexible manipulator using command shaping techniques based on input shaping, lowpass and band-pass filtering. An unshaped bang-bang torque input is used to determine the characteristic parameter of the system for design and evaluation of the control

techniques. Feed-forward controllers are designed based on the natural frequencies and damping ratios of the system. The performance and effect of number of impulse sequences (two-impulse and four-impulses) and filter orders are assessed in term of level of vibration reduction at resonance modes, speed of response, robustness and computational complexity.