OPTIMAL INPUT SHAPING FOR VIBRATION CONTROL OF A FLEXIBLE MANIPULATOR USING GENETIC ALGORITHM

BHUVENDRA A/L RUDRUSAMY

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Faculty of Electrical Engineering
Universiti Teknologi Malaysia

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To my Loving Dad, Mom, Brothers and Sister
To Shantini who makes my journey worthwhile

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ABSTRACT

This thesis presents optimization of input shaping technique for vibration control of a flexible robot manipulator using genetic algorithms (GA). This simulation work is designed in Matlab based environment with sampling frequency of 2 kHz and implemented on a Pentium 4 2.66 GHz processor and the responses are presented in time and frequency domains. The simulation can be repeated for different payload of the system varying from 0 to 100g. In this work, a single link flexible robot manipulator that moves in horizontal plane is considered. Modeling is done using FE method where the system is divided into 10 elements and the damping ratio of the system are deduced as 0.026, 0.038 and 0.040 for the first three vibration mode respectively. The input shaping technique is used to reduce vibrations in the system. This method requires estimated values of natural frequencies and damping ratios to generate impulse sequences. It is noted that the input shaping control technique is a better control technique compared to the bang-bang torque input control technique. It can be further optimized by using GA, by determining the optimal natural frequencies to cancel the resonance modes in the system and thus reducing the vibrations. For input shaping with genetic algorithm (ISGA) versus bang-bang (BB) and ISGA versus input shaping (IS), the percentages of vibration improvement in term of area representation is about 2720.03% and 28.57% respectively. In this work, GA optimization method not only reduces the vibrations, but also reduces time delay. GA can also be used offline or online to tune the system to achieve better performance due to modeling error. However, GA with input shaping technique increases the time and complexity of Matlab simulation.

ABSTRAK

Tesis ini membincangkan pengoptimuman teknik pembentuk masukan untuk kawalan getaran terhadap pengolah lentur robot menggunakan algoritma genetik (GA). Simulasi ini direka berdasarkan Matlab dengan frekuensi persampelan 2 Khz dan dilaksanakan pada pemproses Pentium 4 2.66 Ghz dan sambutannya telah dibentangkan dalam domain masa dan frekuensi. Simulasi ini boleh diulang untuk beban 0 hingga 100 g. Satu cabang pengolah yang bergerak pada satah mendatar dipertimbangkan dalam kajian ini. Teknik finite element (FE) telah digunakan untuk memodel sistem dimana sistem telah dibahagikan kepada 10 elemen dan nisbah redaman 0.026, 0.038 dan 0.040 untuk tiga mod getaran digunakan. Teknik masukan pembentuk digunakan untuk menggurangkan gegaran dalam sistem. Kaedah ini memerlukan nilai anggaran frekuansi tabii dan nisbah redaman untuk menghasilkan susunan impulse. Teknik ini dilaksanakan dengan melingkarkan susunan impulse bersama dengan masukan sistem yang dikehendaki. Teknik kawalan pembentuk didapati lebih baik daripada teknik kawalan bang-bang. Teknik ini juga boleh diperbaiki dengan menggunakan GA dimana GA digunakan untuk menentukan frekuansi tabii yang optima untuk menghapuskan mod salunan, sekali gus menggurangkan getaran. Peratus pembaikan getaran dari segi luas bagi pembentuk masukan dengan algoritma genetic (ISGA) lawan bang-bang (BB) adalah sebanyak 2720.03%, manakala bagi ISGA lawan pembentuk masukan (IS) adalah sebanyak 28.57%. Kaedah pengoptimuman GA bukan sahaja menggurangkan getaran, malah menggurangkan masa lengah. GA juga boleh digunakan dalam talian luar atau dalam untuk menghasilkan prestasi yang lebih baik disebabkan ralat permodelan matematik. Walaubagaimanapun, teknik ini memakan masa dan merumitkan simulasi sistem.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

N	-	Newton
m	-	Meter
mm	-	Millimeter
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_p	-	Payload
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
x	-	Distance from hub
w	-	Elastic deflection
ω	-	Natural frequency
ξ	-	Damping ratio
N_i	-	Number of impulse

A_i	-	Amplitude of impulse
t_i	-	Time of impulse
*	-	Convolution
$F(V_i)$	-	Objection function value
$Eval(V_i)$	-	Fitness value
F_total	-	Total fitness
P_i	-	Probability of selection
Q_i	-	Cumulative probability
r	-	Random number
FE	-	Finite Element method
GA	-	Genetic algorithm
BB	-	Bang-bang torque
IS	-	Input shaping
ISGA	-	Input Shaping using genetic algorithm

LIST OF APPENDICES

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 has been 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).

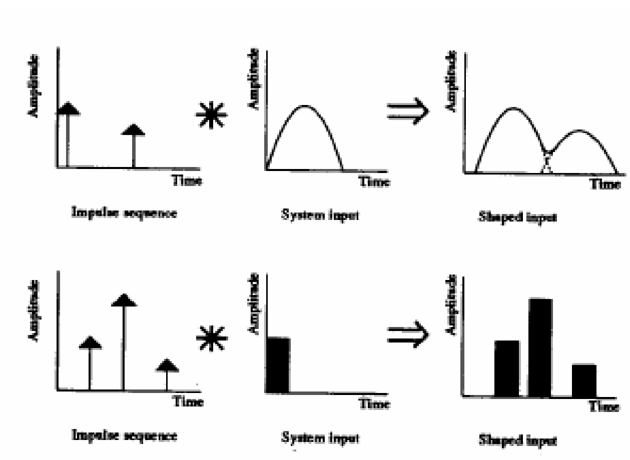

Figure 1.1: Convolution of an impulse sequence with a system input

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 investigate the previous research on input shaping for vibration control of a flexible robot manipulator.
(b) To study the dynamic characteristic of the flexible manipulator in order to construct the controlling method to reduce the vibration.
(c) To introduce a new method in determining the optimal input shaping using genetic algorithms.
(d) To study the performance of a new method for vibration control of a flexible robot manipulator.

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 finite element method will be used. The study is done to understand the dynamic behaviors of the flexible manipulator system. This is very a 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).

1.6 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.

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