FLEXIBLE MANIPULATOR MODELLING AND VIBRATION CONTROL USING END-POINT RESIDUAL VELOCITY FEEDBACK

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To my family

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ABSTRACT

This project presents the modeling and simulation of a two-link flexible manipulator and the control of a single-link manipulator taking into consideration the effects of payload variation on the rate of change of the residual motion of the tip. The characteristic behavior of the dynamic model was investigated in terms of transient response using MATLAB and SIMULINK. The results show that the response of system contains highly undesirable vibrations. In order to reduce this vibration, an Optimized Modified parallel PD controller was proposed using the rate of change as the feedback signal, which is better than acceleration feedback. The Optimized Modified PD involved the use of graphical based Direct search (pattern Search) method to optimized the controllers parameters. It was found out that as the payload increases, the vibration gain also increases, however trajectory tracking met the design specification and vibration was greatly reduced using this algorithm.In comparison to the pure parallel PD, the PPD has a better response time,but was unable to reduce vibration, which makes the OMPD controller better.

ABSTRAK

Projek ini membentangkan model dan simulasi 'two-link flexible manipulator' dan kawalan 'single-link manipulator' mengambil kira kesan perubahan muatan pada kadar perubahan gerakan baki hujung. Ciri-ciri model dinamik telah disiasat dari segi tindak balas fana dengan menggunakan MATLAB dan SIMULINK. Keputusan menunjukkan bahawa tindak balas sistem mengandungi getaran tinggi yang tidak diingini. Dalam untuk mengurangkan getaran ini, sebuah pengawal 'Optimized Modified Parallel PD' telah dicadangkan menggunakan kadar perubahan sebagai isyarat maklum balas yang lebih baik daripada maklum balas pecutan. 'Optimized Modified PD' melibatkan penggunaan 'Direct Search' grafik (Pattern Search) berasaskan kaedah untuk mengoptimumkan parameter pengawal. Saya telah mendapati bahawa dengan peningkatan muatan, berat gegaran turut meningkat, namun pengesanan trajektori bertemu spesifikasi reka bentuk dan getaran telah dikurangkan menggunakan perbandingan algorithm. Jika dibandingkan dengan ' Pure Parallel PD, PPD mempunyai masa tindak balas yang lebih baik, tetapi tidak dapat mengurangkan gegaran, yang menjadikan pengawal OMPD lebih baik.

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LIST OF SYMBOLS

$y_1(x_1, t)$=Total displacement of a point along the manipulator at a distance x_1 from the hub

$w_1(x_1, t)$= Elastic deflection of the hub of link 1

$N(x_1)$,$N(x_2)$= Shape function of link 1 and 2 respectively

$Q_1(t)$,$Q_2(t)$=Nodal displacement of link 1 and 2 respectively

$y_2(x_2, t)$= Total displacement of a point along the manipulator at a distance x_2 from the hub

$w_2(x_2, t)$= Elastic deflection of the hub of link 2

τ_1, τ_2= Applied torque at joint 1 and 2

$u_{j-1}(t), u_j(t)$=Elastic deflections of element

$\theta_{j-1}(t), \theta_j(t)$=Angular displacements of element

ρ_1, ρ_2= Mass density per unit area of link 1 and two respectively

A_1,A_2=Cross-sectional area of link 1 and 2 respectively

E_1, E_2=Young Modulus of link 1 and 2 respectively

I_1, I_2=Second moment area of link 1 and 2 respectively

P_1,P_2=Total potential energy of link 1 and 2 respectively

T_1, T_2=Total Kinetic energy of link 1 and 2 respectively

K_1,K_2=Global stiffness matrix

M_1,M_2=Global mass matrix of link 1 and 2 respectively

n_1, n_2 =Number of elements on link 1 and 2 respectively

l_1, l_2=Length of each in link 1 and 2 respectively

L_1, L_1=Total length of link 1 and 2

m_1, m_2 =Uniform density (mass per meter) of link 1 and 2 respectively.

LIST OF ABBREVIATIONS

PID	Proportional, integral. Derivative
PD	Proportional. Derivative
MPD	Modified Proportional. Derivative
OMPD	Optimized Modified Proportional. Derivative
AMM	Assume Mode Method
FEM	Finite Element Method
ANN	Artificial Neural Network
NN	Neural Network
SLFM	Single Link Flexible Maniputlator
MPC	Model Predictive Control

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Rigid robotic manipulators are designed and built to maximize stiffness so as to reduce vibration and achieve good trajectory tracking [1], and this involves the usage of heavy weight materials. As a result they have a low weight to payload ratio, consequently this affects the operating speed of rigid manipulators, increases the actuator size, increases the overall cost and power consumption. This problem led to the introduction of flexible manipulators which are design with lightweight materials, have a high operational speed, consume less power, and their designing involves the use of small actuators, high weight to payload ratio, less overall cost, and due to their reduced inertial they are safer to operate.

However, the consequence of making lightweight manipulators makes controlling them extremely difficult because their dynamics are complex and non-linear. This is due to the existence of residual vibration in the flexible link manipulators, which explains the residual motion of end effect even when nominal movement has been completed. Also, due to their complexity, it is very difficult to develop an accurate model of flexible link manipulators and non minimum phase characteristics [2].This was one of the major reasons why they were hardly welcomed in manufacturing industries since manipulators are required to have end-point accuracy with respect to the desire trajectory input. So in the design of accurate models and controllers, one must take into account both the rigid and flexural motions of the system [1].

Residual vibration is a serious problem in flexible manipulator systems that are required to carry out precise motion. Residual vibration apart from normal vibration is more dangerous and the level of residual vibration can reduce the performance of the system. To handle this vibration challenge, there have been active researches in this field in finding not only accurate models but also controllers that can reduce or eliminate vibration. In handling general vibration, various control algorithms have been established, which are either passive or active control. Passive vibration control involves mounting of passive materials on the manipulators in order to alter the dynamic characteristics of the system, but this method is only convenient for high frequency and it also increases overall cost of design. Active vibration involves artificially producing sources that absorbs the vibration energy in order the cancel out the effect on the overall system.

Furthermore, control techniques for flexible link manipulators involve either feedback or feedforward control. Closed-loop feedback involving certain output can be use in both trajectory tracking and vibration control, and are widely used because they are not sensitive to changes in parameters and are very good in handling disturbances in systems. Other methods includes the addition of artificial intelligence such Genetic algorithm, Direct search, Fuzzy Logic e.t.c and a combination of one more of these method to eliminate vibration, where certain parameters are automatically tuned online or offline to eliminate vibration, and most of them can be implemented in practice.

1.2 Background of the Problems

Rigid manipulators are easy to model and control, however, flexible link manipulators cannot be modeled as rigid, so accurate control of flexible manipulators is important and a complex problem and it is still an active area of research[3].So obtaining the correct model is very important for an accurate controller to be developed.

A lot of researches have been carried out that examined different control strategy in other to reduce residual vibration and improve trajectory tracking, which prevents the system from reaching the resonance frequency. Flexible manipulators despite their inherent vibration problem, in low speed, vibrations are not important, but in high speed operations, residual vibration becomes a very important factor in terms of trajectory tracking and overall performance of the system. Also, changes in the reference command and external disturbances can also induce vibration. So to achieve accurate control, a proper model is require, and accurate system information is needed and involving intelligent techniques can help reduce unexpected or unforeseen disturbances that may come up in the system.

1.3 Statement of the Problems

The inherent dynamic characteristics and modeling of flexible link manipulators may create errors that may affect the nature of the output response. The accurate trajectory tracking of the end-effectors for precision tasks should involve small vibration level or possible no vibration at all. Therefore, to achieve an accurate dynamic characteristic of the system an accurate mathematical model for the system is required. This is very important in developing control strategies for the manipulator.

Vibration reduction and control has been the core of many researches dealing with flexible link manipulators. Typical solutions in general vibration control involve designing stiff systems and adding dampers to the system, this involves adding extra materials to the original system. Materials such as piezoresistive polymer films and viscoelastic materials have been used as damping sources [4,18].

Different control algorithm involving vibration feedback techniques have also been developed to reduce vibration in flexible link manipulators. Acceleration feedback is one of the vibration feedback signal used in vibration control. An approach involving the design and develop a hybrid learning with acceleration feedback control for end-point vibration suppression of flexible manipulator systems has been used in vibration control [5]. Another vibration feedback control involves the use tip deflection and its rate of change, including the use of neural network to tune certain controller parameters [6]. Other intelligent control methods in addition to classical controllers have been used as well in vibration control. An example involves the use of a combination of Genetic algorithm, Neural network and fuzzy logic with acceleration feedback technique in vibration control [7].

Intelligent control techniques are effective in reducing vibration in close loop system. While most work has been involved on popular intelligent controllers, not much work has been done on Direct search method. Therefore, optimization of a modified classical PD parameters and vibration feedback parameters using Direct search is needed to study its robustness in vibration control.

1.4 Objective of the Study

- Modeling and control of 2 link flexible manipulator using Matlab/Simulink.
- To develop an Optimized Modified PD scheme for trajectory tracking and vibration control respectively.
- To investigate the performance of end-point residual velocity feedback with a control gain in terms of input tracking, vibration reduction level and time response specification.

1.5 Scope of Study

The scope of this study is divided into three main parts:

- The first part involves doing a literature review on flexible link manipulator modeling and control methods use in both trajectory tracking and vibration control.
- Secondly, the developed 2 link flexible manipulator moving in the horizontal plane will be simulated and its open-loop response will be studied to understand the dynamic characteristic of the system.
- A Control strategy for a single link manipulator incorporating payload mass and Hub inertia will be designed and a performance comparative study of the both the parallel PD and Optimized Modified PD will be carried out using Matlab/Simulink.

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