RESONANT CONTROL OF A FLEXIBLE MANIPULATOR SYSTEM

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Dedicated to the my family and friends for their support and prayer towards the successful completion of this study.

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ABSTRACT

A single link flexible manipulator system is a single-input multi-output system. It has a single input as motor torque; and hub angle and tip deflection as outputs. This system is one type of industrial robot which is associated with high vibration and tip deflection due to rigid-body motion and elastic motion during its operation. In this work an integral resonant control was designed using the resonant frequencies of the system to control the vibration and tip deflection. The resonant frequencies are obtained from an experiment using finite element method. These frequencies with their corresponding damping ratios are used to design the resonant controller in such a way to add damping to the system and cancel the effect of vibrations at these natural frequencies of the system. The aim of this work is for the hub angle to track a reference angle without vibration and to achieve low tip deflection. The resonant controller is used as the inner feedback loop to suppress the vibration effect. To achieve zero steady state error an integral control gain is added to the system at the outer feedback loop. Three others control schemes are designed and compared to investigate the control performance of the integral resonant control. These control schemes are fuzzy logic controller, proportional integral controller and pole placement controller. All these control schemes are designed to add damping to the hub to suppress vibration such that the hub angle tracked the reference angle to achieve precise hub angle positioning and regulates tip deflection to zero, with zero steady state error. MATLAB Simulation environment is used to implement the performance of each control scheme. Furthermore, to test the robustness of the integral resonant control as compare with others controllers, different payload values are used to investigate the control performance and compare the results.

ABSTRAK

Sistem manipulator fleksibel satu lengan ialah sebuah sistem satu masukan pelbagai keluaran. Ia mempunyai daya kilas motor sebagai masukan dan hub sudut serta pemesongan tip sebagai keluaran. Sistem ini merupakan sejenis robot industri yang berkait dengan getaran tinggi dan pemesongan tip disebabkan oleh pergerakan badan rigid dan juga pergerakan elastik semasa beroperasi. Dalam kajian ini, kawalan resonan integral telah direkabentuk menggunaan frekuensi resonan daripada Sistem kawalan untuk mengawal getaran dan pemesongan tip. Frekuensi resonan diperoleh daripada ujikaji menggunakan kaedah unsur terhingga. Frekuensi ini bersama-sama nisbah redaman digunakan untuk merekabentuk pengawal resonan secara menambah redaman ke dalam system dan membatalkan kesan getaran pada frekuensi semulajadi Sistem tersebut. Tujuan kajian ini dilakukan adalah untuk membolehkan hub sudut menjejaki sudut rujukan tanpa getaran dan untuk mencapai pemesongan tip yang rendah. Pengawal resonan digunakan sebagai gelung suap-balik dalaman yang hanya berfungsi untuk menghalang kesan getaran. Bagi mencapai ralat keadaan mantap sifar, sebuah kawalan gandaan integral ditambah ke dalam Sistem pada gelung suap-balik luaran. Tiga skim pengawal lain direkabentuk dan dibandingkan untuk mengkaji prestasi kawalan bagi kawalan resonan integral. Skim kawalan yang digunakan adalah pengawal logic kabur, pengawal integral berkadar dan pengawal penempatan tiang. Kesemua skim kawalan ini direkabentuk untuk mencapai kedudukan hub sudut yang tepat dan meregulasi pemesongan tip kepada hampir sifar dan mencapai ralat keadaan mantap sifar. Persekitaran simulasi MATLAB digunakan untuk mengkaji prestasi setiap skim kawalan, mengkaji keteguhan kawalan integral resonan berbanding pengawal-pengawal yang lain. Nilai muatan yang berbeza digunakan untuk mengkaji prestasi kawalan dan membandingkan keputusan.

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SIMO	-	Single Input Multi Outputs
FMS	-	Flexible Manipulator System
IRC	-	Integral Resonant Control
FLC	-	Fuzzy Logic Control
PID	-	Proportional Derivative Controller
PPC	-	Pole Placement Controller
FE	-	Finite Element
E	-	Young Modulus
ρ	-	Mass Density per unit Volume
I	-	Second Moment of Inertia
L	-	Flexible Link Length
L_b	-	Beam Inertia
$\theta(t)$	-	Hub Angle
$\omega(x,t)$	-	Tip Deflection
$Y(x,t)$	-	Tip Position
M_n	-	Mass Matrix
K_n	-	Stiffness Matrix
n	-	Number of Elements
f_i	-	Resonant Frequency
δ_i	-	Damping Ratio
NB	-	Negative Big
NM	-	Negative Medium
NS	-	Negative Small
PB	-	Positive Big
PM	-	Positive Medium
ZE	-	Zero

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Control of flexible manipulators has been an interesting field of research for the past two decades. A significant increase in the number of researches in control of flexible manipulators has been reported. This is due to increase in demand for a high speed industrial robot. The need for a light-weight robot, for industrial applications increases significantly, due to their advantages over heavy weight robot. Some of the advantages of flexible light weight robots are; they can easily be driven by small sized actuator, they consumed less electrical power, high-speed operation, low cost and have light weight. Many novel robotics manipulators applications needs lighter robots that consumed less amount of power for their operation. These types of robot are widely used for space robot, micro-surgery operation and nuclear plant maintenance [1].

However, they have some disadvantages which make their control design very complicated. To achieve precise hub angle positioning and low tip deflection is a complex task especially for the system with varying payload. This is due to their flexible nature which is associated with high vibration and tip deflection during operation. The deflection increases with inclusion, of a payload attached to the link [1]. Another disadvantage is due to elasticity of the system, leading to unwanted vibrations. Figure 1.1 shows a single-link flexible manipulator system used by [2].

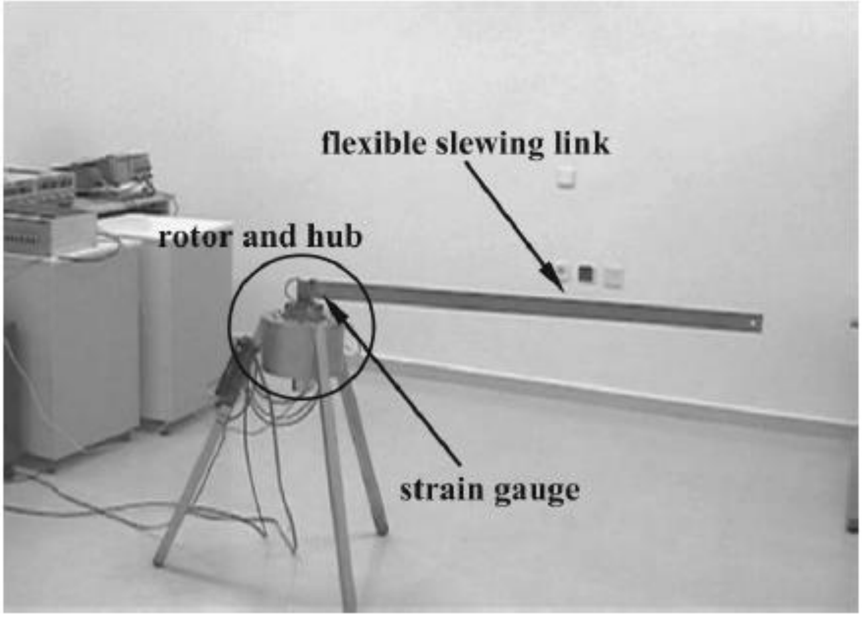

Figure 1.1 Single link flexible manipulator system [2]

There are two main issues that created problems in the designing of flexible manipulator controllers. These problems are: problem due to high order of the systems and due to non-minimum phase dynamics of the system that exist between the tip position and the applied torque at the hub of the system [2].

As a result of the above mentioned problems, researchers implemented many different techniques to solve these problems. Such as Linear Quadratic Regulator (LQR), pole placement, Linear Quadratic Gaussians (LQG), PID controllers, adaptive control techniques, sliding-mode control, neural networks and fuzzy logic control algorithms etc.

In this project, IRC is presented and compared with three other different control schemes. These are FLC, PID controller and PPC controller. The design and implementation is simulated in MATLAB Simulink environment.

1.2 Problem Statement

A flexible manipulator system is a system that operates with high vibration and tip deflection. Moreover, the vibration and tip deflection becomes highly significant when a payload is attached to the flexible link. An efficient control scheme is needed to achieve a precise hub angle positioning with low tip deflection. In addition, the control design is difficult due to high order and non-linearity of the system.

1.3 Objectives

The objectives of this study are:

(i) To study and explore the design of a resonant control, for the control of a flexible manipulators system.
(ii) To design and implement an integral resonant control to control vibration and deflection of the flexible link robot.
(iii) To compare the results of the integral resonant control with other different control schemes and investigate the most efficient control methods.
(iv) To test the robustness of the controllers with changes in payload values, in order to have a better choice of the type of controller.

1.4 Significance of study

Control of flexible manipulator is highly crucial, as the system generates high vibration and high tip deflection during its operation. Since the vibration and deflection are unwanted phenomenal, it becomes highly significant to control these problems, in order to achieve smooth operation of the system.

1.5 Scope and Limitation

In this work the scope and limitations are as follows:

(i) The study is limited to a single-link flexible manipulator system.

(ii) The study involves design of integral resonant control, PD-type fuzzy logic control, PID controller and pole placement control for the control of vibration and oscillation of the flexible link.

(iii) The implementation of the control schemes is limited to MATLAB Simulink environment.

(iv) The scope involves the comparison of the results with different control scheme designed.

(v) Robustness test is performed by considering different payloads.

1.6 Thesis Outline

This thesis is divided into six chapters. In Chapter 1, the overview of this research study is presented. It introduces the flexible manipulator system, its advantages and disadvantages over rigid body robot. Thereafter the problem statement, objectives, scope and limitation of the study are presented.

Chapter 2 presents the related works which are considered as literature review. Different types of control schemes and their implementation are discussed. The proposed control scheme is also presented.

The methodology used in the design and implementation of the proposed control schemes is presented in Chapter 3. The principle and step for the implementations of the control schemes are discussed.

Chapter 4 presents the controller development in which the integral resonant control and the other three control algorithms are designed in details.

Chapter 5 presents and discusses the results and performance of the different proposed control schemes. Performance comparison of the controller's time response and level of vibration reduction is analyzed.

Finally chapter 6 presents a conclusion of this work, suggestion for improvement of the control scheme and recommendation on future works.

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