DYNAMIC CHARACTERIZATION OF A SINGLE-LINK FLEXIBLE MANIPULATOR SYSTEM

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Special dedication to my beloved and respected

father, mother and sister,

who always encouraged, motivated

and inspired me

throughout my journey of life.

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ABSTRACT

Flexible manipulator systems exhibit many advantages over the traditional counterparts. Nevertheless, they have not been preferred in production industries due to its obvious disadvantages in controlling the manipulator. This thesis presents theoretical investigation into the dynamic modelling and characterisation of a flexible manipulator system. A constrained single-link flexible manipulator is considered to move in the horizontal plane only. A mathematical model of the system is developed based on Finite Element method. The final derived model of the system is simulated to investigate the behaviours of the system. From the Bang-bang input signal, the simulated outputs are obtained.

ABSTRAK

Sistem manipulasi mudah lentur mempunyai banyak kelebihan berbanding sistem tradisional yang tegar. Namun, sistem ini jarang digunakan dalam industri disebabkan oleh kelemahannya yang ketara dalam proses pengawalan. Oleh kerana itu, tesis ini memberi tumpuan kepada kajian pemodelan dinamik dan perwatakan sistem manipulasi mudah lentur dari segi teori. Kajian ini hanya mengambil kira sistem manipulasi mudah lentur satu lengan yang bergerak secara mendatar. Model matematik sistem ini dibangunkan berdasarkan kaedah unsur terhingga. Model tersebut disimulasi untuk mengkaji sifat-sifat sistem tersebut. Dari isyarat masuk Bang-bang, keluaran isyarat akan diperolehi.

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ABBREVIATION

DOF	-	Degree of Freedom
FD	-	Finite Different
FE	-	Finite Element
PDE	-	Partial Differential Equation
NASA	-	National Aeronautics and Space Administration
NN	-	Neutral Network
OXY	-	Inertial System of Coordinates
PhD	-	Doctor of Philosophy

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CHAPTER I

INTRODUCTION

Robot manipulators are widely used in most manufacturing and automation industries. This phenomenon is due to their increasing number of applications. Robot was once only used as a device for picking and placing the work pieces. However now, robotic manipulators can be used for completing the complex tasks such as assembling and working for unmanned places. The existing robotic manipulators are designed with the maximum stiffness by using heavy material.

Even though this designed can minimize system vibration and achieve better position accuracy of the robots, these robots are usually heavy with respect to their payload. This condition leads to the limitation speed of robot manipulation's operation, increases the size of actuator, high power consumes, low payload to robot weight load and increases the overall cost.

Flexible manipulators exhibit more advantages over the existing rigid manipulators: they require less material, are lighter in weight, higher manipulation speed, lower energy consumption, require less material, are more transportable, have less overall cost and higher payload to robot weight ratio [1]. These advantages lead to the usage of flexible manipulators for other applications that include in space exploration and hazardous environments.

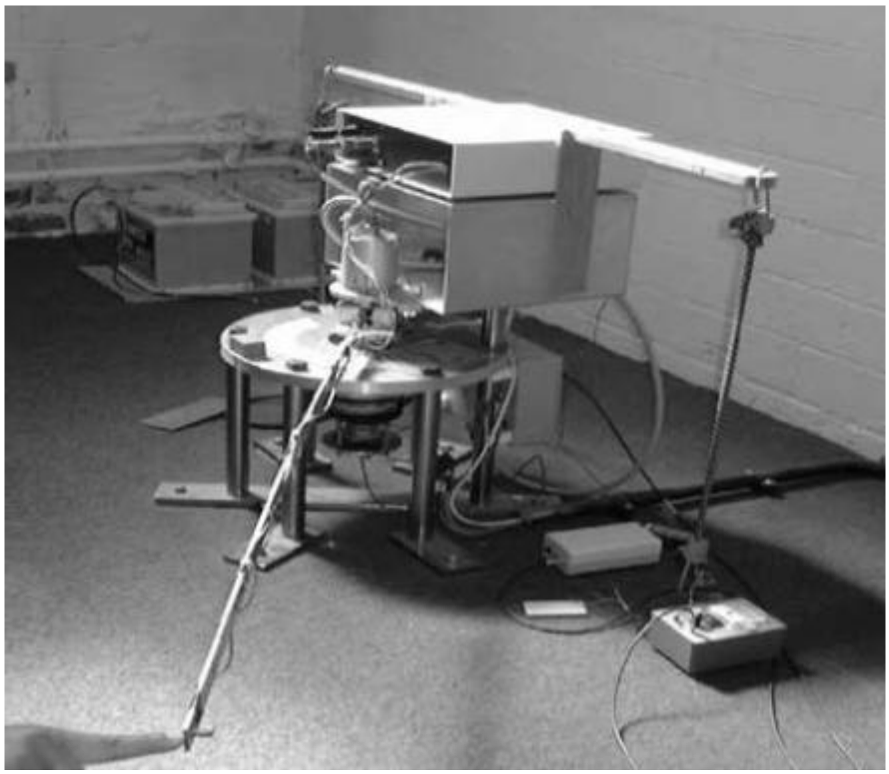

Figure 1.1 Sheffield Flexible Manipulator

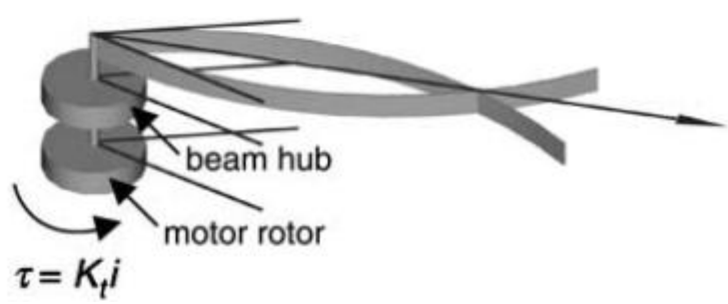

Figure 1.2 Free Vibration of the Manipulator - Sheffield

Figure 1.3 Technical University of Lisbon (IST) Flexible Manipulator

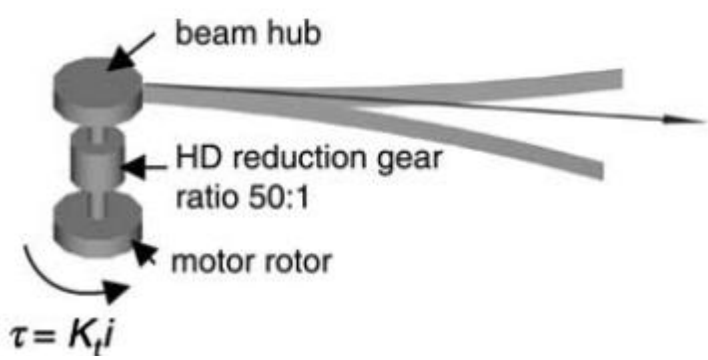

Figure 1.4 Free Vibration of the Manipulator - IST

In space exploration, space robots must be very lightweight to reduce their launching costs to space. In hazardous plants where access to underground storage tanks is limited, flexible-link robots are used in handling hazardous waste.

The actual goal in the flexible manipulator modelling system is to achieve a model that can represent the actual system behaviour. The flexible nature of the system is highly non-linear and complex. Problem arises due to the precise positioning requirement, vibration due to system flexibility, the difficulty in obtaining accurate model and non-minimum phase characteristics of the system [2]. Hence, a control mechanism that accounts rigid and flexural motions of the system is required in order to maintain the end-point positional accuracy.

Nevertheless, the problem arises when a flexible manipulator carries a payload. Practically, a robot is requires to perform a single or set of tasks in sequence such as to pick up a payload, move to a specified location or along a pre-planned trajectory and place the payload. However, the dynamic behaviour of the manipulator is significantly affected by payload variations [3]. Accurate models and efficient controllers need to be developed in order to attain the existing advantage that associated with the lightness of robotic manipulators.

Before proceeding a mathematical model that involves in several effects which include damping, inertia and payload, it is important to recognize the flexible nature and dynamic behaviour of the system. A good control algorithm needs to be designed after obtaining an appropriate model. There are various approaches have been used in order to solve problems regarding on the flexible nature behaviour. The modelling approaches can be divided into two main categories which are:

- Assumed Mode Method (AMM).
- Numerical Analysis Approach.

AMM is widely used in modelling of flexible manipulators. This approach is used to obtain approximate modes by solving the Partial Differential Equation of dynamic behaviour's characterizing system. The Lagrange equation is used in order to derive the dynamic model of a structure.

A differential equation can be obtained and it can represent as a summation modes. Each mode is assumed as a product of two functions which are for the distance along the length of the manipulator and a generalized co-ordinate dependent upon time. It has been reported that the first two modes are sufficient to identify the dynamics of flexible manipulators [4].

The previous studies have been proved using utilized approach of the AMM for modelling a single-link flexible manipulator [4]. The Eigen model's values agreed with the experimentally determined frequencies of the vibrational model. However, the model does not always represent the fine details of the system [5].

Numerical analysis approach is based on Finite Difference and Finite Element methods and they are commonly used in a flexible manipulators modelling system. The simulation studies with Finite Difference method have been proved by using simple mathematical terms. Moreover, these studies have shown the relative simplicity of the method [6]. This method involves discretizing the system into several sections and also developing a linear relation for the deflection of each section using Finite Difference approximations.

The Finite Difference approach has been utilized in obtaining the dynamic characterization of a single-link flexible manipulator system which incorporating damping, hub inertia and payload [7]. The Finite Element method is well-used in solving many material and structural problems.

This method involves discretizing the actual system into a number of elements with the associated elastic and inertia properties of the system. This leads to the approximate static and dynamic characterization of the system. The usage of this method in modelling the flexible manipulators has been previously. These investigations have shown that Finite Element method can obtain a better representation of the system than Finite Difference methods. Furthermore, the Finite Element method exhibits several advantages over the Finite Difference method in terms of accuracy and computational requirements [8]. However, the effects of structural damping and payload have not been satisfactorily addressed.

1.1 Objective of the Project

The main goal of this project is to derive a dynamic model of a single-link flexible manipulator by using Finite Element method. The thesis emphasis on obtaining a customized model that satisfies the Finite Element method that used to obtain the dynamic model. It is also to simulate and validate the dynamic model of the system. The simulation will be performed using MATLAB and SIMULINK. The last objective is to investigate the dynamic behaviour of the flexible manipulator according to the simulation results which are end-point displacement and hub angle signals.

1.2 Problem Statement

The existing robotic manipulators that are designed with the maximum stiffness can minimize system vibration and achieve better position accuracy of the robots. However, the usage of heavy material is usually heavy with respect to their payload. The flexible nature of the system is dynamically complex and several problems arise due to the nature flexibility system.

These problems involve in precise positioning requirement, vibration due to system flexibility, the difficulty in obtaining accurate model and non-minimum phase characteristics of the system. One approach needs to be precisely chosen in order to solve the flexible manipulators modelling system.

The performance of the Finite Element methods in modelling the flexible manipulators has been previously investigated. These investigations show that this method can be used to obtain a good representation of the system. It has been proved that a single element is sufficient to describe the dynamic behaviour of a flexible manipulator. By using a single element, the first two modes of vibration can be well described. However, the effects of structural damping and payload have not been satisfactorily addressed.

1.3 Scopes of Project

This project focuses in modelling a single-link flexible manipulator without payload and damping which moves in the horizontal plane only. The dynamic model of the system is described by using Finite Element method. By using Lagrange's equation, the dynamic model is represented in state space form, so that it can be solved by using the control system approaches. The final derived model of the system is simulated using MATLAB and SIMULINK in order to investigate the behaviours of the system.