THE DEVELOPMENT OF EMBEDDED BAND-STOP FILTER FOR VIBRATION CONTROL OF A FLEXIBLE MANIPULATOR

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ABSTRACT

This project presents an investigation into development of feed forward control scheme for vibration control of a flexible manipulator using band-stop (IIR) filter technique using Xilinx (Spartan 3E) . A constrained planar single-link flexible manipulator is considered in this project and the dynamic model of the system is derived using assumed mode method. A bang-band torque input signal is used to determine the characteristic parameters for designed and evaluate for vibration control technique. The band-stop filter algorithm is designed with sampling frequency of 1000 Hz and cut off frequency between 10 Hz to 300 Hz. After that, it is embedded in Field Programmable Gate Array board using Xilinx software. This algorithm is then applied to the flexible manipulator in the Simulink through PCI 1710 HG DAQ Card. The experimental results presented in time and frequency domain. The effects of the filter order in band-stop performance are also investigated. Finally, a simulation of band-stop filter is compared to the embedded filter onto FPGA board.

ABSTRACT

Projek ini mempersembahkan kajian berkaitan pembangunan skim kawalan depan melalui aplikasi penapis bandstop dengan menggunakan perisian Xilinx ISE 10.1 (Spartan 3E) untuk mengawal getaran bagi sebuah manipulator robot boleh lentur. Sebuah kekangan manipulator boleh lentur satu-hubung telah digunakan dan model system dinamik telah dibentuk dengan menggunakan kaedah anggaran mod. Tenaga putaran digunakan untuk menetukan parameter khusus untuk mereka dan menilai teknik kawalan getaran. Seterusnya, algorithme bagi penapis bandstop dengan contoh frekuensi 1000 Hz dan memotong frequensi diantara 10 Hz sehingga 300 Hz. Selepas itu, ianya akan ditanam ke dalam papan 'Field Programmable Gate Array' (FPGA) dengan menggunakan perisian Xilinx ISE 10.1. Kemudian, algorithme ini akan di applikasikan ke atas manipulator boleh lentur dalam Simulasi melalui PCI 1710 HG DAQ Card. Keputusan simulasi tersebut akan dipersembahkan dalam domain masa dan frekuensi. Selain itu, kesan tertib perbezaan pada penapis bandstop terhadap prestasi sistem telah dikaji. Akhirnya, satu penilaian perbandingan diantara simulasi penapis bandstop didalam perisian Matlab dengan penapis bandstop yang ditanam didalam papan FPGA.

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LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
DSP	Digital Signal Processing
FPGA	Field Programmable Gate Array
FDATool	Filter Design & Analysis Tool
HDL	Hardware Description Language
Hz	Hertz
IIR	Infinite Impulse Response
I/O pin	Input Output pin
rad	Radian
Sec	Second
m	Meter
N	Newton
Mm	Milimeter
I	Area moment of inertia
E	Young Modulus
ρ	Mass density per unit volume

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Most existing robot manipulators are designed and built in manner to maximize stiffness, in attempt to minimize system vibration and achieve good positional accuracy [1]. High stiffness can be achieved by using heavy material. So as a consequence, such robots are normally heavy with respect to the operating payload. So, it will be effectuate the limits the operation speed of the robot manipulation, increases the actuator size, boost energy consumption and increase overall cost. In order to solve these problems, the new robotic system is designed to be lightweight and passes some level of vibration. Flexible manipulator in feedforward schemes exhibits many advantages over their rigid counterparts where they are use cheaper and lighter material, lower power consumption, have manipulation speed, and safer to operate due to inertia. This project is focused to the feedforward schemes based on band-stop filtering technique. The differences order of band-stop filter is applied to produce an input function that can reduce the vibration. A bang-bang torque input also applied to determine the characteristics of flexible manipulator design. Then, the algorithm of the filter will be embedded in Field Programmable Gate Array (FPGA) before applied to flexible manipulator in Simulink model. The response of the flexible manipulator is presented in frequency and time domain.

1.1.1 The Flexible Manipulator System

A description of the single-link flexible manipulator system considered in this work is shown in Figure 3.1, where XOY and POQ represents the stationary and moving co-ordinates frame respectively and τ represents the applied torque at the hub. E, I, ρ , A, h I and p M represents Young modulus, area moment of inertia, mass density per unit volume, cross-sectional area, hub inertia and payload mass of the manipulator respectively. In this work, the motion of the manipulator is confined to the XOY plane. Since the manipulator is long and slender, transverse shear and rotary inertia effects are neglected. This allows the use of the Bernoulli–Euler beam theory to model the elastic behavior of the manipulator. The manipulator is assumed to be stiff in vertical bending and torsion, allowing it to vibrate dominantly in the horizontal direction thus, the gravity effects are neglected. Moreover, the manipulator is considered to have constant cross-section and uniform material properties throughout. In this study, an aluminium type flexible manipulator of dimensions 900 x 19.008 x 3.2004mm^3, E =71.10$^9 N/_{m^2}$, I = 5.1924m^4 and ρ = $2710kg/_{m^3}$ is considered [1].

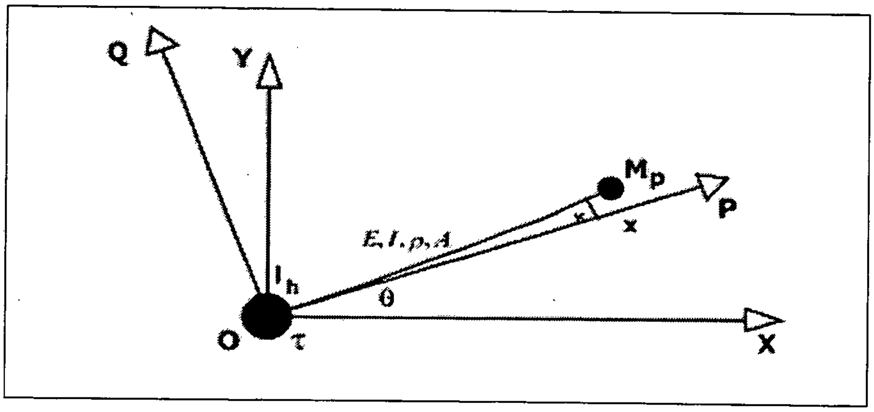

Figure 1.1: Description of manipulator system

1.2 Problem Statement

Most existing robot manipulators are designed and built in manner to minimize stiffness, in attempt to minimize system vibration and achieve good position accuracy [1]. High stiffness can be achieved by using heavy material. So as a consequence, such robots are normally heavy with respect to the operating payload. So, it will be effectuate the limits the operation speed of the robot manipulation, increase the actuator size, boost energy consumption and increase overall cost. In order to solve these problems, the new robotics is designed to be lightweight and pass some level of the vibration. However, the control of flexible manipulator is an extremely challenging problem. Problem according to maintain precise positioning requirement, vibration due to system flexibility, the difficulty in obtaining accurate model of the system and non-minimum angle characteristics of the system [1,3]. Therefore, flexible manipulators have not been favored in production industries. 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 are efficient controllers have to be develop.

1.3 Objective of the Project

A flexible manipulator has a problem arise due to control the vibration reduced and to maintain the accurate positioning. To solve this problem, a few objectives were created in the project. The objective of this project is to:

- Develop a band-stop filter algorithm using Field Programmable Gate Array (FPGA) board for vibration control of flexible manipulator.
- Investigate the performance of the filter with difference order band-stop.

1.4 Scope of the Project

The scope of this project is divided into the three parts. The first part is to study the dynamic characteristics of flexible manipulator. The existing dynamic model using assume mode method will be used. This part is very important to understand the dynamic behavior of flexible manipulator in order to design a good controller.

The second part is to find the best order of band-stop filter algorithm to control the vibration of a flexible manipulator. The 2^{nd}, 4^{th} and 6^{th} order of band-stop filters are involved. This work will be carried out through simulation using Matlab.

The last part of the study is to develop the band-stop filter algorithm into Field Programmable Gate Array (FPGA) using VHDL code. Then, the band-stop filter algorithm will be verified.

1.5 Thesis Outline

This thesis is composed of five chapters covering introduction, literature review, methodology, analysis and result and the last chapter is a conclusion and recommendation in future work.

Chapter 1 explains the background of the project, problem statements, objective and also the scopes. Dynamic characteristics of flexible manipulator and the difference order are main controller for control vibration.

Chapter 2 focused on the literature review for those parts that has been explained in Chapter 1. All the journals and books that are related to this project are used as a reference to guide and help completing this project. Each of this part is explain based on this finding.

Chapter 3 explains and discuss about the methodology that has been used in order to complete this project. There are two parts in this chapter which are the software development and hardware implementation. The discussion will be focusing on how to convert program from Matlab to VHDL code and developing the code on Spartan 3E board.

Chapter 4 will gives a result and analysis on the design for the system which consists SIMULINK filter using Matlab, and Xilinx.

Chapter 5 discussed the conclusion of development of this project. This chapter also discusses the recommendation for this system for future development or modification.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focused on the literature review for the component in this project. 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 filter technique

Input shaping improves response time and positioning accuracy by reducing residual vibration in computer controlled machines. The method requires only a simple system model consisting of simple estimates of the natural frequencies and damping ratios.

Method to control vibration of a flexile manipulator can be classified into feedforwad and feedback technique. The feedback technique use measurement and estimation of the system states to vibration reduced [1]. So, it often the most desirable means of eliminating vibration. But, in this project, only the feedforward technique is applied.

Feedforward technique for vibration control of flexible manipulators consists of developing the control input through consideration of physical and vibration properties of the system, so the vibration at response modes can be reduced. This technique uses the utilization of Fourier expansion. This statement can be proof with the previous research. Aspinwall used the Fourier expansion for the forcing function to reduced peaks of frequency spectrum at discrete points [2]. Controlling technique vibration of flexible manipulator was design based on frequency vibration and damping ratio for the system. However, the first natural frequency is considered as the dominant characteristic the dynamic behavior of the single link flexible manipulator system [3]. The band-stop filter designed based on these techniques for processing the bang-bang torque input. Butterworth filter are most often use in the control the vibration because it have achieved the nearest lower natural frequency. So, in this filtering technique, the high level performance can be achieved with low-pass filter compare with the band-stop filter [4]. However, the input shaping is the most effective way the vibration control of a flexible manipulator.

Singhose and Pao [5] had compared the control methods between a shaped bang-bang input with the response of using the time-optimal flexible-body commands. As a result, they found that the shaped bang-bang applied in the command shaping provides extremely increased robustness to modeling errors while being much easier to implement

2.3 Filter Design Criteria

If at least one of the coefficients {an} has non-zero value, then the filter is Infinite Impulse Response (IIR) Filter. IIR Filter capable to meet a given set of specifications with a much lower filter order than that of a corresponding FIR filter, but they introduce larger total delay [6]. An appropriate filter must have a pass-band (response equal to 1) for the lowest frequencies and a stop band (response equal to 0) for frequencies equal or higher of the natural frequency. This type filter is called low-pass filter.

Several methods are used to design IIR filters (to calculate the coefficients {cn} and {an} that can approximate the desired frequency response. Most of these methods make use of analog prototype filters, such as the Butterworth or the elliptic prototype. Filters designed using these methods have non-linear phase and they introduce large delay [10].

2.4 Review of implementation Digital filter in FPGA

Infinite impulse response (IIR) filters are widely used in digital signal processing systems due to the following causes. IIR filters are rigorously analogous to well known and widely used analog filters. In most cases IIR filters are implemented by signal processors and ASICs, which architecture is adapted to filtering algorithms. For a long time IIR filters represent applications of FPGAs in the digital signal processing [7].

Implementation IIR filters in FPGA has a set of advantages, such as full adaptation of implemented in FPGA structure to the filtering algorithm, high throughput, hardware utilization effectiveness, achieving high rate of calculating precision.

2.5 Summary

After study the several previous researches on vibration control of flexible manipulator most of the methods use observation from the simulated or experimental dynamic characteristic of the flexible system. Then, from the characteristics of the system, the suitable order and references modes are determined to design the filter input.

CHAPTER 3

METHODOLOGY

3.1 Introduction

There are the important parts to determine the methodology in order to develop this project to make sure this project can be finished according to the guidelines and still on the track especially based on an objectives and scope of the project. Methodology also known as the step from the beginning what actually this project is required and the step to how to implement part by part such as design the band-stop filter in Matlab and embedded to Xilinx software using FPGA Board. Figure 3.1 below show the block diagram for the whole system of this project and simple explanation how it operates.

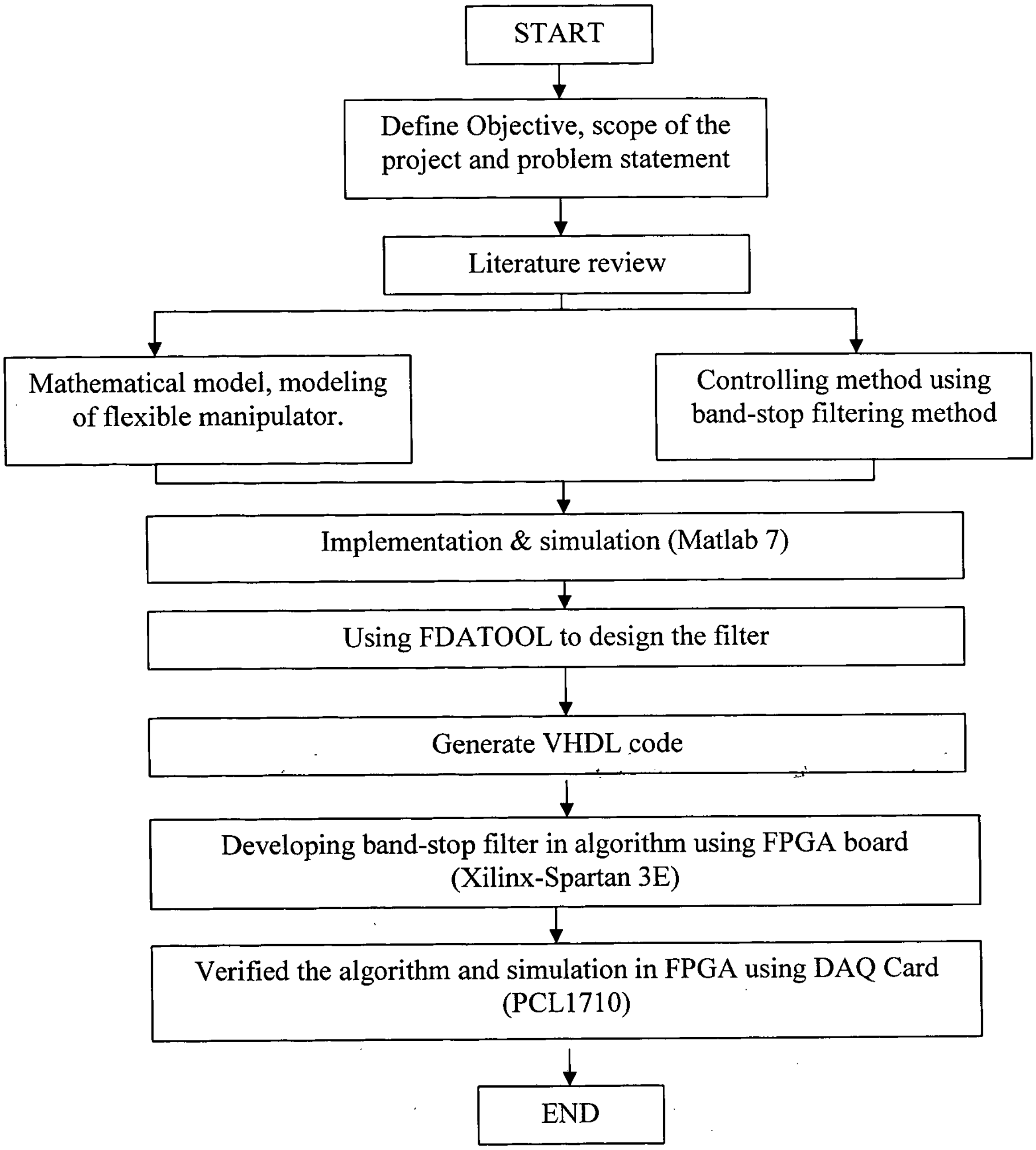

Figure 3.1: Flow chart for the overall project

In this project, the filter that was used is IIR Band-Stop Filter (Butterworth). This filter will control the vibration of flexible manipulator. To get the output, the digital filter is implemented in FPGA Board. The diagram of the system for this project is shows below:

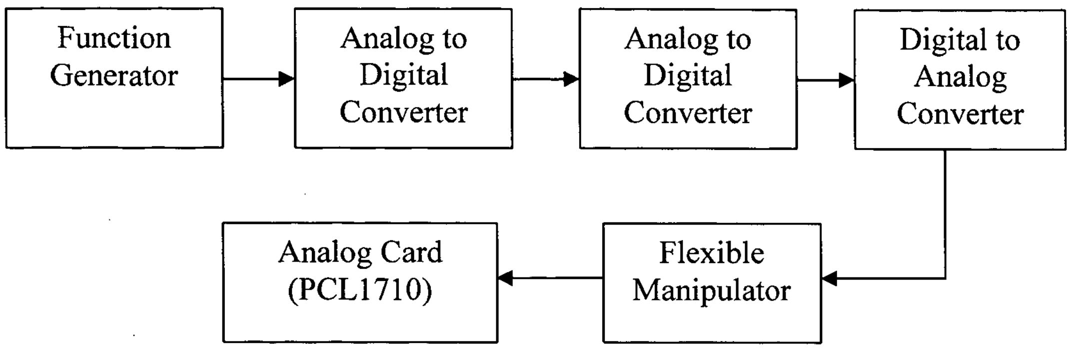

Figure 3.2: Block Diagram of the System

3.2 Software Development

In order to finish this project, software development is one of the important parts that should be considered before interfacing with the hardware. The software that uses in control the vibration is Matlab 7, Xilinx ISE Design Suit 10.1 and PCL 1710. It is important to show the result for the simulation and it will show in graph diagram.

3.2.1 Matlab Simulink

Simulink provides a graphical user interface for building math models as block diagrams. The graphical interface is popular for developing dynamical models for many fields, such as electronics, hydraulics, chemistry, and especially, control systems.[8]

Simulink is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing.[9]

Before set up the real project, the simulation result must be done first and this result should be compared with the experimental result that produced from the analog card. MATLAB Simulink was used for the simulation part. It has an analog filter design block in MATLAB Simulink. The important thing in this simulation is to determine the lower cut-off frequency (f_L), higher cut-off frequency (f_H) and center frequency for band-stop filter where it will be used when to design the new band-stop filter using FDATool.

Beside that, the bang-bang input also important in the system where it will act to generate the input signal in the system. The parameter for the flexible manipulator also must be fill in to see the changes of vibration without filter and with band-stop filter. The performance of band-stop filter is investigated in term of the acceleration, angle, displacement and velocity. The transfer functions for the filter is:

2nd order

$$G(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2} \qquad (1)$$

$$\frac{0.0018s^2 + 81}{0.0018s^2 + 0.0127s + 81} \qquad (1.1)$$