THE DEVELOPMENT OF EMBEDDED LOW-PASS FILTER FOR VIBRATION CONTROL OF A FLEXIBLE MANIPULATOR

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ABSTRACT

This project presents an investigation into developing feedforward control scheme for vibration of a flexible manipulator using low pass (IIR) filter technique using Xilinx ISE 10.1 (Spartan 3E). A constraint planar single link flexible manipulator is considered in this project and dynamic model of the system is derived using assumed mode method. A bang-bang torque input signal is used to determine the characteristic parameters for designed and evaluate for vibration control technique. The low pass filter algorithm is designed with sampling frequency of 1000 Hz and cut-off frequency 20 Hz. After that, it is embedded in Field Programmable Gate Array (FPGA) board using Xilinx ISE 10.1 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 low pass performance are also investigated. Finally, a simulation of low pass filter in Matlab is compared in the embedded filter onto FPGA board.

ABSTRAK

Project ini mempersembahkan kajian berkaitan pembangunan skim kawalan depan melalui aplikasi penapis 'low pass' 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 sistem dinamik telah dibentuk dengan menggunakan kaedah anggaran mod. Tenaga putaran digunakan untuk menentukan parameter khusus untuk mereka dan menilai teknik kawalan getaran. Seterusnya, algorithme penapis 'low pass' dengan contoh frequensi 1000 Hz dan memotong frequensi 20 Hz. Selepas itu, ianya akan ditanam ke dalam papan 'Field Programmable Gate Array' (FPGA) dengan menggunakan perisian Xilinx ISE 10.1. Kemudian, algorithme ini akn diaplikasikan ke atas manipulator boleh lentur dalam similasi melalui PCI 1710 HG DAQ Card. Keputusan simulasi tersebut akan dipersembahkan dalam domain masa dan frequensi. Selain itu, kesan tertib perbezaan pada penapis 'low pass' terhadap prestasi sistem dikaji. Akhirnya, satu penilaian perbandingan diantara simulasi penapis 'low pass' di dalam perisian Matlab dengan penapis 'low pass' yang ditanam di dalam papan FPGA.

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x'	-	derivative of the state vector with respect to time
x	-	state vector
y	-	output vector
u	-	input or control vector
A	-	system matrix
B	-	input matrix
C	-	output matrix
D	-	feedforward matrix

LIST OF ABBREVIATION

FPGA	-	Field Programmable Gate Array
ADC	-	Analog Digital Converter
DAC	-	Digital Analog Converter
Eq.	-	Equation

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CHAPTER 1

INTRODUCTION

1.1 Background of the Project

Flexible manipulators are known of their advantages over conventional rigid robotic arms which it used cheaper and lighter material, lower power consumption, higher manipulation speed, and more safer to operate. There are a lot of research have been made for controlling the vibration but lots of trouble occur to maintain the precise positioning requirement, vibration due to system flexibility, the difficulty in obtaining accurate model of the system and non minimum phase characteristics. Due to the complexity and nonlinearities in attain the accurate position, flexible manipulator have not been favored in production industries. Therefore a control mechanism is needed for both rigid body and flexural motion of the system. There are two types of vibration control which are feedforward and feedback control. Vibration that happen in the system can be characterized by measuring one or more frequencies that are excited by the motion transient using feedforward control technique. This control technique can reduce the vibration of the mechanical system. By using

this technique, there is neither additional sensor nor actuator being used. There is a lot of method being used to reduce the vibration such as input shaping or filter. For input shaping, a shaped torque input is developed on the basis of extracting the input energy around the natural frequency of the system, to reduce the vibration. On the other hand, filter has been noted that it can provide greater flexibility in reducing the vibration. While this experiment will be focusing on low pass filter technique to reduce the level of vibration although it has been shown that better performance. Low pass filter with cut-off frequency will cut the first vibration mode at certain percentage. The simulation results of response of the manipulator to the filter input are presented in frequency time and domain.

There are three common filter was design it is Butterworth, Chebyshev, and Elliptics and this project will used Butterworth filter. Each of the filters is different including the filter order where this may effects the vibration angle, displacement, velocity and acceleration.

1.2 Objective

The objectives of this project are:

(i) To develop a low pass filter algorithm using FPGA board for vibration control of flexible manipulator.

(ii) To investigate low pass filter with different number of order

1.3 Scope

There are three main scope of this project which is the first scope is to study the dynamic characteristic of the flexible manipulator. The assumed mode method is used to derive the dynamic model of the system. In design a good controller, the behaviors of flexible manipulator should be understand.

Then, the input filter of low pass filter algorithm, have to be studied where the project will use Butterworth type in design the model system. In addition, the filter order of 3^{rd} order, 6^{th} order and 9^{th} order are studied to understand the different between them and their effect towards manipulator vibration.

Next part of the scope project is develop the simulation using Matlab, this will give first graph before experiment it in and simulink using VHDL code and embedded in the FPGA board using Xilinx softaware. Then the low-pass filter algorithm will be verified and analyze.

1.4 Problem Statement

A flexible manipulator was design to maximize stiffness, minimize vibration and achieve good positional accuracy but the consequence of non linear and complexity of the system the flexible manipulator cause the increasing of vibration. Although the flexible manipulator has been design with lower power consumption, higher manipulation speed, and more safer to operate it have been difficulties to achieve and maintain the accurate positioning. All of the problems due to attain the precise position, system flexibility, obtain accurate

model and no n minimum phase characteristic make the flexible manipulator have not been favoured by production industries.

1.5 Thesis Outline

This thesis consists of five chapters including this chapter. The contents of each chapter are outlined as follows:

Chapter 1 explained the overview of the project, objective, scope and also the problem statement.

Chapter 2 contains a detailed of literature review that refer while finish this project. It is including the information about Low pass filter, Field Programmable Gate Array (FPGA), Xilinx ISE, and VHDL Code.

Chapter 3 includes the project methodology. This will explain about the simulation part, converting VHDL code in Matlab, program the FPGA, converting the signal from ADC to DAC. And output showed in Advantech

Chapter 4 discussed the result of simulation by using MATLAB Simulink, the result for the system and also the problem that face in this project. Chapter 5 discussed about the conclusion and the recommendation of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Flexible Manipulator

Nowadays, the flexible manipulator challenge is to reduce the vibration of the system. The vibration problem being faced by all engineers because the system is vibrate when it is being pushed off over the limit. Then, the idea of design a good controller came to solve the vibration where low-pass filter is one of the possibilities to control the vibrations.

2.2 Review of Low-Pass Filter Method

Low pass filter improves response time and positioning accuracy by reducing vibration in computer controlled machine. The command shaping based

in filter technique is developed on the basis of extracting input energy around natural frequencies of the system using filtering techniques [2]. Therefore, the filtering techniques used for pre-processing the input signal so that no energy is fed into the system at natural frequency [2]. It has a pass band at the lower frequencies determine by the pass band frequency limit *fb*, and stop band at the higher frequencies determine by cut-off frequency *fc*. At certain cut-off frequency, low pass filter will be design to attenuate the input energy at all frequency above the cut-off frequency. M.A. Ahmad, Z. Mohamed, and Z.H. Ismail, in their research said that the cut-off frequency at 20% for the first vibration mode was designed to ease the input energy at all frequency. In addition, 50% of the first vibration will be cut-off by using third order (3^{rd} order) low pass filters therefore the cut-off frequencies of the filter were selected at 1.6 and 2.2 Hz [2]. The filter technique can reduce the amplitude of the vibration at resonance modes of the system, with the rotation of the hub angle, acceleration, velocity, and displacement. There are some reason of low pass filter is quite different in the actual implementation [1].

There are a three method have been used to present the minimum vibration where there are Park-McClellan method, Chebyshev method, and Least Squared method [1]. In case to reduce the vibration the filter order also will be change where it will be studied the 3^{rd} order, 6^{th} order and 9^{th} order. This project will be held using FPGA while several researched that have been done used Matlab to represent the effect of filter in reducing the vibration [3]. Plus, different filter being used where this project will be held using Butterworth filter. Different filter used will effect the frequency response in size and distribution ripple in the stop band [1]. In this project, feedforward system is proposed to control the vibration of the flexible manipulator. Feedforward system will directly give input to low-pass filter and towards the system plant. While feedback system will have control structure comprises two feedback loops then the loop will be combined to produce torque input [2]. The different between feedforward and feedback is feedforward will investigate the robustness of the system as it been expected to be more robust compared to feedback [2]

2.3 Field Programmable Gate Array

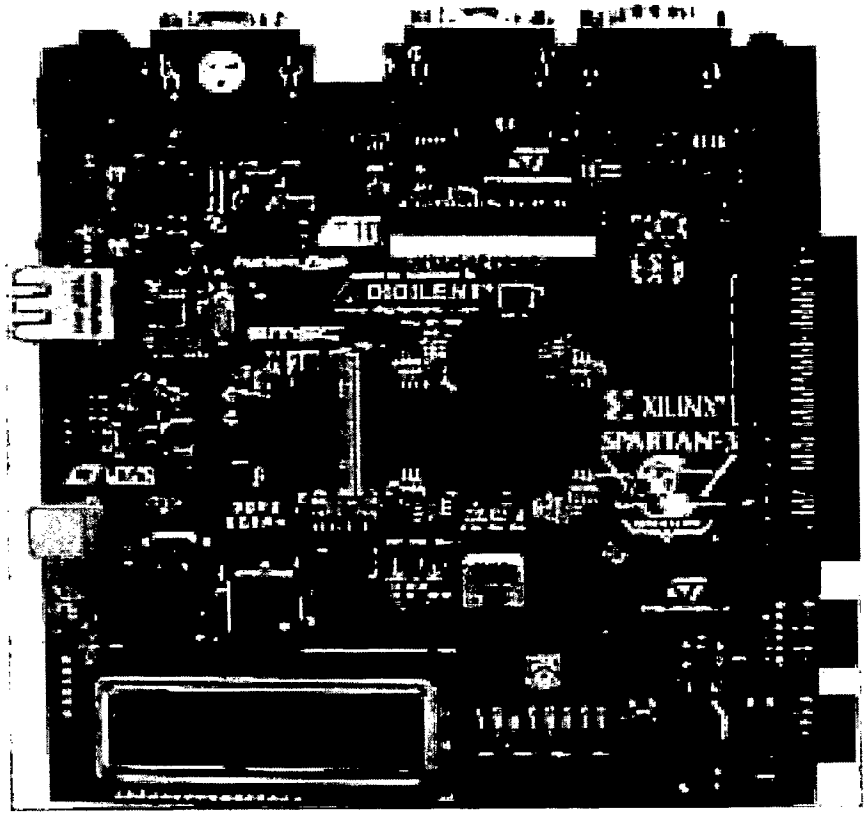

Figure 2.1: Field Programmable Gate Array

Figure 2.1 is a Field Programmable Gate Array also known as FPGA is an integrated circuit designed to be configure by the customer or designer after manufacturing. FPGA evolved out of CPLD (Complex Programmable Logic Device) chips where it implements much more complicated function than CPLD [5]. It contain components called 'logic block', a hierarchy of reconfigurable interconnects that allow the blocks to be 'wired together' which like a chip programmable breadboard. The logic block will be either simple logic gates, such as AND, XOR, and NOT or complex combinational functions. It also includes memory elements which may be simple flip-flop or complete blocks of memory.

On an FPGA instead of interpreted and executed instructions by a processor, algorithm was constructed from the blocks of hardware logic. Plus, the architecture of FPGA allow for the simultaneous, parallel execution of multiple tasks. Those factors prove that FPGA can execute certain algorithms much faster than it could on CPU [5]. In term to define the behavior of FPGA, users provide Hardware Description Language (HDL) or a schematic design. Then, the description will be synthesize to produce a binary file (using the software provided by manufacturer) used to configure the FPGA device [5].

FPGA application will include digital signal processing, software define radio, aerospace and defense system, medical imaging, computer vision, speech recognition, cryptography and other applications. The application can be finds in any are or algorithm that can makes use of the massive parallelism offered by designer. The inherent parallelism of the logic resources on an FPGA allow for considerable computational throughput even at a low MegaHertz (MHz) clock rates.

2.4 Hardware Description Language

Hardware description language (HDL) has certain advantage where it allow user to describe and verify the functioning of a system before implemented in the hardware. It also allow for the concise description of concurrent system, with multiple subcomponents all operating at the same time. HDL also allow for more flexible and powerful expression of system behavior [5].

Hardware description language (HDL) that commonly used in FPGA design are VHDL also known as VHSIC Hardware Description Language which is abbreviation for Very High Speed Integrated Circuit and Verilog. VHDL develop

from the Ada programming language, and has a relatively verbose syntax and it is strongly type and case insensitive [5]. On the other hand, Verilog evolved out of the C programming language where it is much more concise compared to VHDL language. Though, both languages are highly similar in functionality and widely supported by software synthesis tools.

This project has chosen to use VHDL as a language to describe and synthesis the FPGA. VHDL was choose because it will detect the certain error that will not been detected by Verilog during synthesis. VHDL is used today in digital hardware design process, from specification through high-level function simulation, manual design, and logic synthesis down to gate-level simulation. It will be effectively used with methodology and toolset. The two main kinds of tools set which operate on VHDL language are simulation and synthesis. The Language Reference Manual (LRM) will define each simulator must do with each part of the language.

The benefits of using VHDL are its executable specification, the tools and technology. VHDL can execute its specification in order to achieve high level of confidence in its correctness before commencing design, and may simulate one to two orders of magnitude faster than a gate level description. VHDL descriptions of hardware design and test benches are portable between design tools, and portable between design centres and project partners. It also permits technology design through support for top down design and logic system. Although VHDL has a lot of advantages in its functionality, its still have some disadvantage where it not suited for specialized implementation-level design verification tools such as analog simulation, switch level simulation and timing simulation.

CHAPTER 3

METHODOLOGHY

3.1 Introduction

This project is to control the vibration of flexible manipulator which commonly used in robot system using analog low pass filter. This project can be separated into 3 main parts there is: methodology

i. Simulation Part
ii. Design the low pass filter
iii. Implement the VHDL in FPGA

Figure 3.1 below shows the flowchart for the overall project.

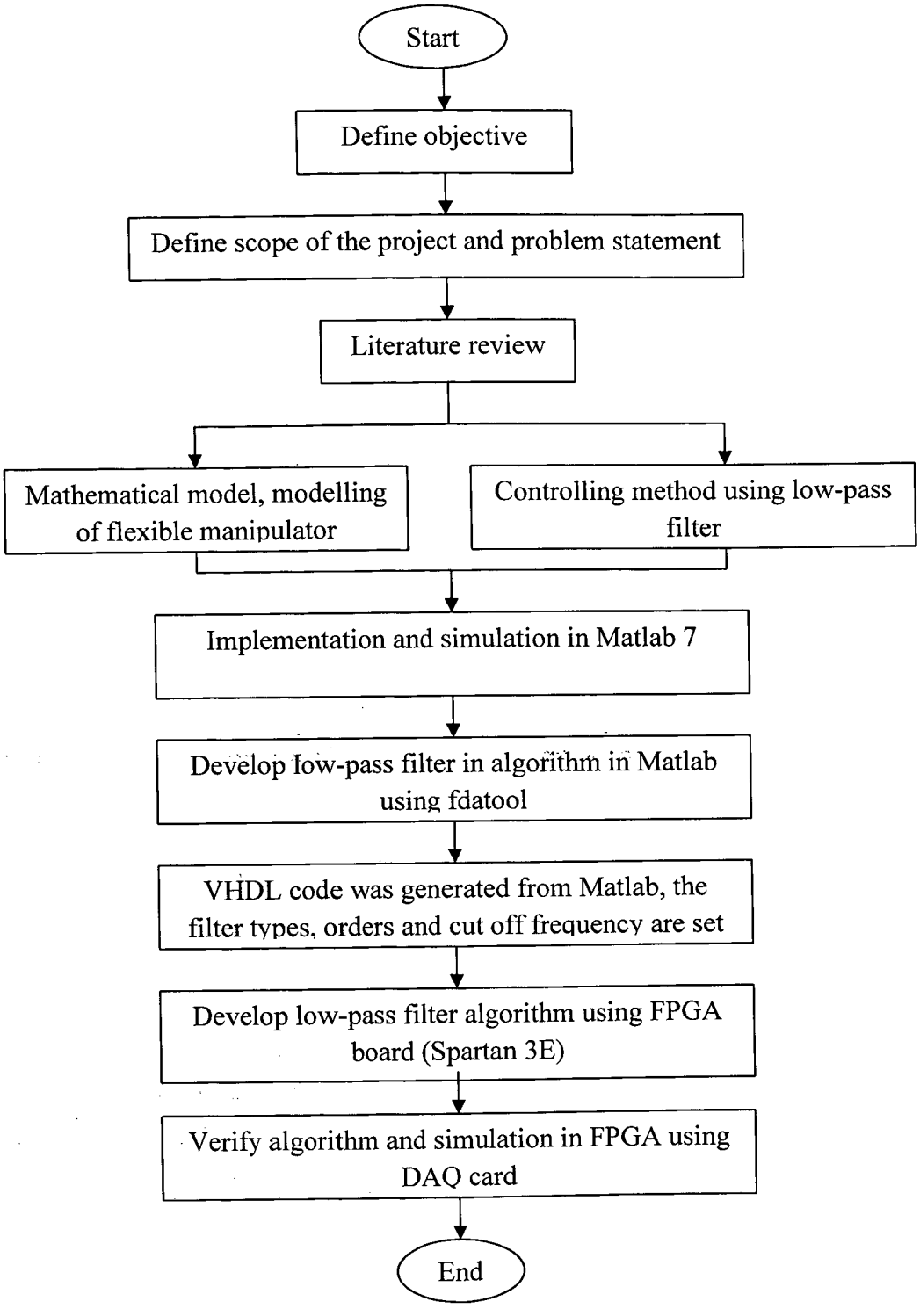

Figure 3.1: Flowchart for overall project

In this project, the low pass filter algorithm was design in FPGA Spartan 3E to control the vibration flexible manipulator and find the order that suitable to the designed filter. The ADC (analog-to-digital converter) was used as the signal that produce from function generator will be analog while FPGA only accept digital input therefore ADC will be used to convert the input signal. On the other hand, DAC (digital-to-analog converter) will convert the digital signal from filter output that produce from FPGA to analog since the output needed in flexible manipulator is analog signal. Thus, in order to develop the filter a simulation was done in Matlab.

The diagram simulation of the system for this project is shown in Figure 3.2:

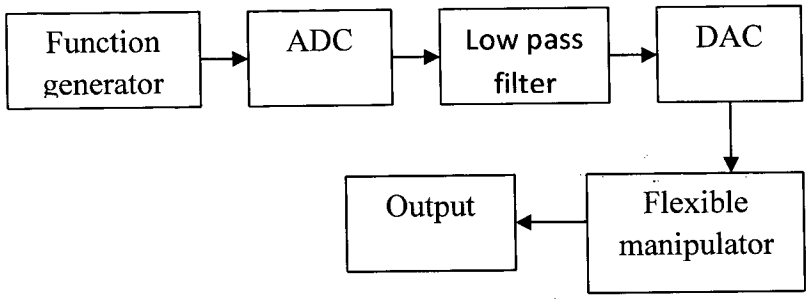

Figure 3.2: Block Diagram of the System

3.2 Simulation Part

Before set up the real project, the simulation result must be done first and this result will be compared with the FPGA result. MATLAB Simulink is used for the simulation part. It has an analog filter block in MATLAB Simulink. The important thing in the simulation is the mathematical model of the flexible manipulator which is model in state space form. The state space equation is showed eq. (1) :