HEXAPOD ROBOT MOTOR CONTROLLER USING FPGA

FIKRI NAIM BIN MOHD ROSLI

This report is submitted in partial fulfillment of the requirements for the award of Bachelor of Electronic Engineering (Computer Engineering) With Honors

Faculty of Electronic and Computer Engineering

University Technical Malaysia Melaka

JUNE 2012
Tajuk Projek : Hexapod Robot Motor Controller Using FPGA

Sesi Pengajian : 1 / 1 / 12

Saya .......................................................... (HURUF BESAR)

mengaku menbenarkan Laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan ( √ ) :

☐ SULIT*

☐ TERHAD**

☐ TIDAK TERHAD

*(Mengandungi maklumat yang berdaerah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

**(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

Disahkan oleh:

(TANDATANGAN PENULIS)

(TANDATANGAN PENYELIA)

(TARikh: 14/6/202)

(TARikh: 14/6/2012)
"I hereby declare that this report is result of my own effort except for quotes as cited in the references."

Signature: 

Name: FIKRI NAIM BIN MOHD ROSLI

Date: 14/6/2012
"Hereby declare that I have read this report and in my opinion this report is sufficient in terms of the scope and quality for the award of Bachelor of Electronic Engineering (Computer Engineering) With Honors.”

Signature: ...................................................

Supervisor’s Name: PN. NUR ALISA BT. ALI

Date: 14/6/2012
For my lovely mum and dad, thanks for sacrifice towards my success.

For my supervisor, Pn. Nur Alisa Bt. Ali, thanks for all your supports

To my friends who’s helped me lots, I’ll appreciate very much
ACKNOWLEDGEMENT

First and foremost, I would like to give Thanks to ALLAH SWT, for helping me. I would like to express my appreciation to my supervisor, Pn. Nur Alisa Bt. Ali for her support and guidance throughout this whole project. To my beloved parents who always give me support and never tired of convincing me in order to achieve my determination and finishing my study without any delay. They always support me and understand me while giving me opportunity in completing all my projects. Besides that, I am also thankful to all the lecturers that also giving me some ideas and knowledge that can be used to accomplish the PSM project. Not forgotten to my friends who had also helped me in giving their thought, pro and contra of each of the research and result that had obtained. Once again for the last time, I would like to express my gratitude to those people that already mentioned above as well as the BENC’s student Faculty of Electronic and Computer Engineering who provide many suggestions, information, and criticism and sustain in this report.
The project is Hexapod robot motor controller using FPGA. This project will be use a single chip system (FPGA) to control all the motors in movement of the Hexapod. FPGA is use to replace conventional microcontroller which have limited PWM signal. The movement for the Hexapod will use servo motor. Servo motor can give a natural and precise movement. With FPGA, single chip is enough to control all the servo motors. Hexapod robot is a six-legged robot with each leg consists of three servos motor that act as actuators for the movement. The main focus of this project is how the servomechanism can be generated by using FPGA based system. The algorithm movement of the Hexapod robot is closely configured and design with three main aspect. The aspects are stability, speed and synchronization of eighteen servos motor. Lastly, the project will be discussing how can FPGA based system can replace the conventional PIC microcontroller for servo motor.
ABSTRAK

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>DESCRIPTION</th>
<th>PAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROJECT TITLE</td>
<td></td>
<td>i</td>
</tr>
<tr>
<td>DECLARATION</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td></td>
<td>vi</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>CONTENTS</td>
<td></td>
<td>ix</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xiv</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td></td>
<td>xvii</td>
</tr>
<tr>
<td>LIST OF APPENDIX</td>
<td></td>
<td>xviii</td>
</tr>
</tbody>
</table>

1 INTRODUCTION 1

1.1 OVERVIEW 1

1.2 OBJECTIVES 2
# PROBLEM STATEMENT
2

# SCOPE
2

# BRIEF EXPLANATION OF METHODOLOGY
3

# REPORT STRUCTURE
5

## LITERATURE REVIEW
6

### INTRODUCTION
6

### HEXAPOD ROBOT
7

#### Leg Coordination
7

#### Single Leg Controller
8

#### Degrees of freedom
9

### SERVO MOTOR
9

#### Servo Motor Operation
10

#### Servo Wiring
11

#### Servo Voltage
11

#### Servo Current
12

#### Servo Velocity
12

#### Servo Selection
12

#### Servo Motor Tuning
13
III METHODOLOGY

3.1 INTRODUCTION 18

3.2 FLOWCHART OF PROJECT METHODOLOGY 19
  3.2.1 Literature Review 20
  3.2.2 Hexapod Movement Algorithm 21
  3.2.3 Verilog code 26
  3.2.4 Thesis writing 27

3.3 PRELIMINARY RESULT 28

IV RESULTS AND DISCUSSION 30

4.1 PRELIMINARY RESULT 30

4.2 EXPECTED RESULT 31

4.3 PROGRAMMING THE LEG ALGORITHM 31

4.4 SIMULATION RESULTS 34
  4.4.1 Hardware Assignment and Testing 40
# LIST OF TABLES

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Table 1: Movement for time T1</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>Table 2: Movement for time T2</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>Table 3: Movement for time T3</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>Table 1: Movement for time T1</td>
<td>24</td>
</tr>
<tr>
<td>5</td>
<td>Table 2: Movement for time T2</td>
<td>24</td>
</tr>
<tr>
<td>6</td>
<td>Table 3: Movement for time T3</td>
<td>24</td>
</tr>
<tr>
<td>7</td>
<td>Table 3: Movement for time T4</td>
<td>25</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Figure 1: Basic block diagram of project</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Figure 2: Flow-chart of project methodology</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Figure 3: Actual image of the project Hexapod robot</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>Figure 4: Example of Hexapod robot leg</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Figure 5: Servo motor from HiTEC HS-55</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>Figure 6: Diagram of pulse widths sent to control servo motor position</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Figure 7: Closed-loop velocity servo</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>Figure 8: Measuring open-loop characteristic</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>Figure 9: LP-2900 Development kit</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td>Figure 10: Basic Spartan-II Family FPGA block diagram</td>
<td>15</td>
</tr>
<tr>
<td>11</td>
<td>Figure 11: Relationship of PWM signal and servo motor</td>
<td>17</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Figure 12: Project methodology flowchart</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Figure 13: Block diagram of the Hexapod robot</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Figure 14: Top angle of the Hexapod robot with positions of all servo motor</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Figure 15: Example of movement of the servo motor</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Figure 16: Example of new project wizard in Xilinx ISE</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Figure 17: Example of Verilog source program</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Figure 18: Example of PWM module in Xilinx ISE</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Figure 19: Verilog programming for generating a PWM</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Figure 20: Code to do a continuous pulse count</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Figure 21: Comparing pulse count to generate pulses</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Figure 22: Example of complete Verilog programming of RC Servo PWM signal generation</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Figure 23: Parameter assign as follows</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Figure 24: PWM out pin assignment</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Figure 25: PWM signal generation by overflowing the accumulator</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Figure 26: Declaration for full rotational for the servo</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Figure 27: 180 degree waveform generate in ModelSim</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Figure 28: Declaration for neutral position</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Figure 29: Waveform for neutral position</td>
<td></td>
</tr>
</tbody>
</table>
30 Figure 30: Declaration for -180 position
31 Figure 31: Waveform for -180 position
32 Figure 32: Full waveform for simulation of the PWM output signal.
33 Figure 33: Flowchart for the whole program
34 Figure 34: Register transfer level schematic
35 Figure 35: Inside the RTL schematic
36 Figure 36: View of RTL technology
37 Figure 37: Pin assignment for the project
38 Figure 38: Successful design flow
39 Figure 39: Program into FPGA chip package
40 Figure 40: Actually board with input/output indicator
41 Figure 41: SW1 is "0" and SW2 "1" meaning switch 1 is activate
42 Figure 42: Waveform when switch 1 (01) is pressed.
43 Figure 43: Declaration for testbench taken from Verilog module
44 Figure 44: Initializing input to do a testbench for our module.
45 Figure 45: Hexapod robot movement direction
46 Figure 46: Pin assigned in Xilinx ISE 10
LIST OF ABBREVIATIONS

DOF - Degree of Freedom
DC - Direct Current
PWM - Pulse Width Modulation
CCW - Counter Clock Wise
CW - Clock Wise
FPGA - Field Programmable Gate Array
HDL - Hardware Description Language
LED - Light Emitting Diode
RTL - Register Transfer Level
## LIST OF APPENDIX

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Hexapod movement</td>
<td>52</td>
</tr>
<tr>
<td>B</td>
<td>Program algorithm</td>
<td>55</td>
</tr>
<tr>
<td>C</td>
<td>Program codes</td>
<td>57</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Overview

This project is about designing, implement and utilizing FPGA based servo motor control for the movement of Hexapod. This project will be focusing on the servomechanism of the Hexapod robot. This robot could move through uneven terrain with speed, stability and synchronization of the robot movement are prioritized. Together with capability to move uneven terrain, the robot has the flexibility to move into isolated places with ease. XILINX Spartan-II XC2S50 chip is used as brain or main controller to control the servos motors. The controller will manipulate the 6-legs of the robot. Servos are used because of the accuracy in determining the angle of the legs to provide stability for the movement.
Each leg is actuated by three (3) servos which makes 18 servos in total. Hexapod means that the robot will be have 6 legs (Hex). An array of algorithm will be program to make the Hexapod move.

1.2 Objective

Objective of the project are to design algorithm of movement, implement and the design of FPGA based servo motor control for the movement of Hexapod.

1.3 Problem Statement

A robot walks on six legs can be describe as Hexapod robot. Each leg consists of 3 servos which make 18 servos in total. Most of servo control are using PIC based controller. The use of PIC is no longer relevant as there are too many servos to control and to make the hexapod movement more precisely. Therefore, we need to control and achieve multiple servo control synchronization. Using FPGA base controller, we can get a precise movement of control for all servo motor. Others micro-controller like PIC have limited number of servo motor control. Therefore need more than one IC need to be utilized all the servo control for the whole operation. Furthermore, micro-controller like PIC needs larger board size and magnifying the use of discreet IC.

1.4 Project Scope

In this project, the system for the controller of the Hexapod movement is developed using FPGA architecture. The language for the FPGA programming is using Verilog programming. The controller will control eighteen servo motor in total.
1.5 Brief Explanation of Methodology

The methodology of this project is made to determine the objective of the project and ensure it will not derail from project’s scope. Beginning of the project, literature review and background study is made. This is to ensure what, why and how the FPGA based system is different from conventional PIC microcontroller system. Furthermore, this will lead to problem solving method for problem statement that occurs for PIC based Hexapod robot motor controller.

After that, the FPGA architecture is study and familiarize. Study on block diagram of the FPGA and the LP-2900 experiment kit which hold the FPGA chip and input/output module on it are made and documented. Basically the controller for this project is place on LP-2900 Spartan II board. On that board have input/output module. The expected use of input are the switches where it control the movement of the Hexapod, while the output will be connected to the eighteen servos motor at each six-leg of the Hexapod. Then, basic PWM signal for control motor movement will be design and developed.

Next step for project methodology is the most crucial for Hexapod development. The algorithm for each leg to move is carefully design and constructed. Movements were insect-inspired where three crucial aspects are look into. Stability, speed and synchronization of all servos motor are coming into place. This is to ensure the
fluidity of the Hexapod movement to move at all terrain and all direction. The servomechanisms that make the Hexapod move are actually generated by the FPGA and this make the FPGA is ideal for Hexapod motor controller.

Figure 2: Flow-chart of project methodology

After the algorithm of the Hexapod movement is designed, the next step is to implement it on simulation using Xilinx ISE and ModelSim PE software. The language used is Verilog programming language. By using software, the result can be determined via simulation. This is to ensure not to waste time to troubleshooting during
implementation on the FPGA board itself. If the implementation is succeeded, the end result must be check to see whether it is still within the scope of the project and if it does the project can be classify as successfully delivered.

1.6 Report Structure

This report consists of three chapters which are Introduction, Literature Review, and Methodology. 

In Chapter 1 is Introduction, discussed about project background, project objectives, problem statement, scope of work, short brief of project methodology and overview the remaining chapters.

In Chapter 2 is Literature Review, reviews some references from previous project, journals, articles, books and datasheet. All the materials was useful to success this project. 

In Chapter 3 is Methodology, where flow process of project had been discussed this project is divided into two parts software development and hardware design. The details process for the both part will be presented in this chapter 3.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, about the Hexapod robot, the leg coordination FPGA based controller, degree of freedom and the servomechanism theory is discussed. The background study or literature review come from various resources such as:

1. Senior’s past project thesis
2. Books
3. Journals

But in some cases, resources like online article, video and images also contribute to the better understanding and concrete theory for this project.