

FPGA-BASED HEXAPOD ROBOT CONTROLLER

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Tajuk Projek : FPGA-BASED HEXAPOD ROBOT CONTROLLER

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APPROVAL

“I acknowledge that I have read this report and in my opinion this report is sufficient in term of scope and quality for the award of Bachelor of Electronic Engineering (Computer Engineering) with Honours.”

Signature :

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ABSTRACT

Field Programmable Gate Array is widely applied and is more preferable for robot platform as the major requirement is the massive reconfigurable capability. Conventional implementation of multiple servo motors would require multiple chip setups such as master-slave configuration or I/O expansion. However, by using FPGA, the single chip FPGA system is able to control all the movement of the servo motors. FPGAs use dedicated hardware for processing logic and due to the parallel paths processing, different operations do not have to compete for the same processing resources. Hence, the speed can be very fast indeed, and multiple control loops can be run on a single FPGA device at different rates. In this project, the Hexapod Robot is a six-legged robot whereby each leg consists of 3 servo motors which work as a driving mechanism for the movement. The gait controller is developed to synchronize the position and direction of the servo motor at every state of movement. The main focal point of this project is to control and improve the generation of PWM signals on the servomechanism by using FPGA based system. Furthermore, the hexapod robot is developed to achieve several movements such as standing, forward and reverse.

ABSTRAK

FPGA digunakan secara meluas dan lebih sesuai untuk landasan robot sebagai keperluan utama disebabkan oleh kebolehan pembentukan semula. Perlaksanaan konvensional dalam pelbagai motor servo akan memerlukan kebanyakan cip seperti konfigurasi “master-slave” atau pengembangan I/O. Namun, dengan penggunaan FPGA, sistem cip FPGA tunggal dapat mengawal semua pergerakan motor servo. FPGA digunakan untuk menumpukan perkakasan untuk logik pemprosesan dan disebabkan oleh pemprosesan laluan selari, operasi yang berbeza tidak perlu bersaing untuk sumber-sumber pemprosesan yang sama. Oleh itu, kelajuan pasti menjadi sangat cepat dan pelbagai gelung kawalan boleh dijalankan pada peranti FPGA tunggal pada kadar yang berbeza. Dalam projek ini, Hexapod robot adalah sebuah robot berkaki enam di mana setiap rangkaian tersebut terdiri daripada 3 motor servo yang berfungsi sebagai mekanisme memandu pergerakan itu. Pengawal langkah dibangunkan untuk menyelaraskan kedudukan dan arah motor servo pada setiap pergerakan. Tumpuan utama projek ini adalah untuk mengawal dan meningkatkan penjaan isyarat PWM pada mekanisme servo dengan menggunakan sistem berasaskan FPGA. Tambahan pula, hexapod robot ini diciptakan untuk mencapai beberapa pergerakan seperti berdiri, ke hadapan dan belakang.

DEDICATION

For my beloved family, project supervisor, lecturers and friends that always believe in me to complete this project and report.

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LIST ABBREVIATION, SYMBOLS AND NOMENCLATURES

FPGA	-	Field Programmable Gate Array
IC	-	Integrated Chip
I/O	-	Input Output
HDL	-	Hardware Description Language
VHDL	-	VHSIC (Very High Speed Integrated Circuit) Hardware Description Language
PWM	-	Pulse Width Modulation
ISE	-	Integrated Synthesis Environment
USB	-	Universal Serial Bus
AC	-	Alternating Current
DC	-	Direct Current
EEPROM	-	Electrical Erasable Programmable Read Only Memory
RAM	-	Random Access Memory
DCM	-	Digital Clock Manager
DSP	-	Digital Signal Processing
SPI	-	Service Provider Interface
JTAG	-	Joint Test Action Group
CLB	-	Configurable Logic Blocks

IEEE	-	Institute of Electrical and Electronics Engineering
FPS	-	Frame per Second
CPLD	-	Complex Programmable Logic Device
LUT	-	Lookup Table
RTL	-	Register Transfer Level
CW	-	Clockwise
CCW	-	Counter-clockwise
PIC	-	Peripheral Interface Controller

CHAPTER 1

INTRODUCTION

This chapter presents the background of the study, problem statement, objective of the study, and the scope of project. The background of the study is focused on the working method of developing hexapod on FPGA's IC. The problem statement reveals the impact of different controller boards to the system. In the objectives, the intention of this study is to propose a hexapod robot controller for improving the performance and quality of the system. At the end of this chapter, the scope of study highlights the focus and mechanism of the project.

1.1 Project Overview

This project involves the development of hexapod robot controller using FPGA's integrated circuit. The basic requirements of the system include the simple programming method, numerous supports and hardware availability of various types of motors and design boards. In consideration of developing the robotic platform, adequate number of output ports in the microcontrollers with respect to the number of servo motors required by the system is the main design issue. The flexibility element in the reconfigurable hardware such as Field Programmable Gate Array would create a single chip solution for embedded system design where all the hardware modules could be instantiated in one FPGA chip. This leads to a complete control on the hardware synthesis of the design and determination of required I/O ports for the particular controller of a robotic system. This project focused on the

design and implementation of a servo motor controller in an FPGA platform. The main design issue is to determine the adequate number of output ports with respect to the number of servomotors applied in this system. However, the number of available output ports allocated by manufacturers is fixed. Despite the methods or solutions of increasing the output ports such as master-slave configuration and port multiplexing are viable; it would require extra board space to accommodate the extra chips and peripherals. Therefore, instead of employing a fixed number of ports' microcontroller, a preferable reconfigurable hardware allows circuit designer to instantiate any hardware modules of the design by programming using Hardware Description Language. The term reconfigurable indicates that the existing circuit design could be reconfigured or redesigned when it is necessary. As a result, designer has a complete control on the synthesis of the design and able to define the I/O ports required for the particular controller in the robotic platform. The alteration of I/O ports could be made without changing the physical state of controller chip. The controller is then interfaced with 18 servomotors which are equipped with a Hexapod robot. PWM pulses are generated for each of the servomotor controller in order to determine the exact position of the servos in relation to the robot's movement. The controller design is programmed in Verilog, synthesized, translated, mapped and place-and-routed using Xilinx's Integrated Software Environment (ISE) Design Suite.

1.2 Problem Statement

Common hexapod robot is controlled by discrete conventional microcontroller whereby the configuration is fixed and has a limitation such that any additional features that need to be included to the Hexapod robot would require new chip replacement due to I/O constraint. The sequential nature of program execution in microcontroller would significantly affect the synchronization of the Hexapod movement. A parallel execution of the motor would ensure more precise movement of the Hexapod robot.

1.3 Objectives of Project

Design a Hexapod controller in FPGA environment and establish the movement mechanism.

1.4 Scope of Project

In this hexapod robot, each of the legs consists of 3 servo motors that work as actuators for the movement. Most often, hexapods are controlled by gaits, which allow the robot to move forward, turn, and side-step. The gait controller is designed to synchronize the position of servomotor in relation to its particular movement. Controlled design is programmed in Verilog, which will then be translated, synthesized, mapped, placed and routed using Xilinx ISE. Simulation and verification are done using HDL Simulator (Isim Simulator) and the generated bit file will be programmed on the Spartan-6 FPGA chip.

CHAPTER 2

LITERATURE REVIEW

This chapter extend the literature reviews that cater the information in accordance with the objectives of this project. This section includes the following elements: determination of a stable gait analysis, implementation of real-time hardware on FPGA chip, control servomotors through pulse-width modulation (PWM) signals. The relevant information and other extra features were gathered as shown below.

2.1 Introduction

In this chapter, there will be discussion and description of information that is related to the objectives of studies. This section includes the following elements such as the hexapod robot, signal processing, simulation, modelling, and control. In the robot section, definition, type and application of hexapod robot will be described. Humans naturally adjust their walking style to suit their movement or terrain they are walking on. For example we intuitively know from our past experience to walk slowly and carefully on slippery ice but can run fast on grass. Meanwhile, legged robots exhibit similar behaviour and are able at traversing a variety of terrains.

2.2 Hexapod Robot

In industry, robots are categorized into several types based on different aspects such as arm geometry, power sources, applications, control techniques, and path control. It is due to the fact that robots are designed to perform required tasks in any particular situation. However, the type of robot that would be discussed below is the type which is classified based on the degree of capability and smoothness.

Hexapod, a six legged robot has been developed with varying degrees of capability, complexity and expense. Gait establishment has always been an issue in constructing an operative and effective hexapod robot. The leg coordination FPGA based controller, degree of freedom and servomechanism will be discussed.

Hexapod robot is one of the most typical robots because it is possible to study many kinds of gaits with different speeds and loads. The main advantage of this robot is it is able to perform task with greater mechanical flexibility. This flexibility is very interesting to develop several autonomous and high-reliability works. The project will be unique from other ordinary robots since a six legged robot making is capable of it capable of doing many different tasks. In comparison, other hexapods tend to be simply a body and legs and are designed onto to move around. In the development of these kinds of robots in early times the use of two degrees of freedom limbs was adopted, which limit the mobility of the robot, but the evolution of Hexapod robots occurs when three degrees of freedom legs were adopted with the controller improvement and the use of efficient power systems and servo motors.

2.3 Servo Motor

Servomotor is a rotary actuator that provides a precise movement. It also allows for precise control of angular position, velocity and acceleration. Servomotor commonly is small in size, but is very energy-efficient and able to give a big punch. Because of this advantage, they can be used to operate robots, airplanes and the other electronic device. There are two types of servo motors, AC and DC. AC servo can control and handle higher current surges, therefore, is more likely to be used in industrial machinery. DC servos are not designed for high current surges and are usually better suited for smaller application. Servomotor also has been used in industrial application, manufacturing and food services. Inside the pretty simple set-up of servo motor: a small DC motor, potentiometer and a control circuit. A

servomotor consumes power as it rotates to the commanded position and will immediately turn to whatever angle the controller instruct it. Servomotor can be controlled by sending an electrical pulse of variable width, or pulse width modulation (PWM), through the control wire. Servo motors are able to rotate only 90 degrees in either direction for a total of 180 degrees movement. For the natural position, it was defined as the position where the servo motor has the same amount of potential rotation in the both the clockwise (CW) or counter-clockwise (CCW) direction. When the servo motor is commanded to move from the original position, they will move to the new position and hold that position. The servos will not hold them position forever though, and to make it happens, means to make it hold in current position, the position pulse must be repeated to instruct the servo to stay in position.



Figure 2.1 Servo Motors are available in a wide variety of sizes, torque and speed ratings.

2.4 Papilio One

The Papilio One is an open-source FPGA development board based on the Xilinx Spartan 3E FPGA. It consists of 48 I/O lines, dual channel USB, integrated JTAG programmer, 4 power supplies and a power connector.

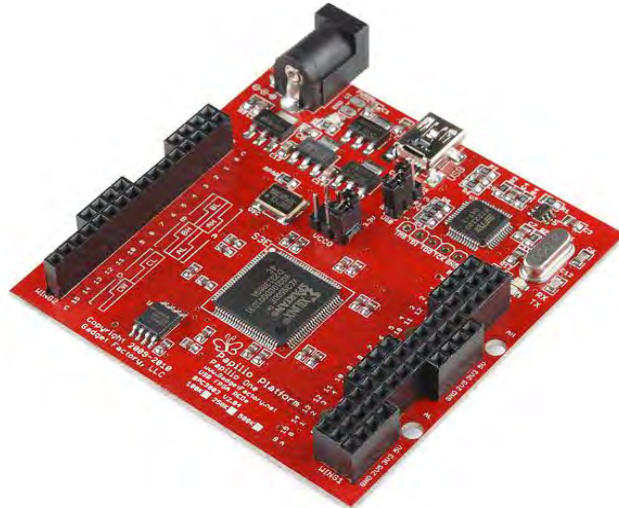


Figure 2.2 The Papilio One is an expandable development board for design and prototyping of unique ideas.

The features and specifications of papilio one are listed as follows:

2.4.1 Power

- Four independent power rails at 5V, 3.3V, 2.5V and 1.2V.
- Power supplied by a power connector of USB.
- DC Input Jack.
 - Input Voltage (recommended): 6.5-10V

2.4.2 USB

- Two channel USB connections for JTAG and serial communication implemented with FT2232D.
- EEPROM memory to store configuration settings for the FT2232 USB chip.

2.4.3 Spartan 3E FPGA

- 32MHz oscillator that can be used by Xilinx's DCM to generate any required clock speed.
- VTQHP-100 footprint that supports Xilinx XC3S100E, XC3S250E, and XC3S500E parts.