HEXAPOD CONTROLLER USING MICROPROCESSOR CORE IN FPGA

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ABSTRACT

The design and implementation of the soft-core processor in FPGA is developed to control Hexapod robot. In many applications, the soft-core processors provide several advantages over the custom designed processors such as reduced cost, flexibility, platform independence and greater immunity to obsolescence, but the main reason of implementing soft-core processor in FPGA for this project is to provide an option in modifying the I/O layout and the internal architecture without replacing the microcontroller board. The conventional microcontroller in Hexapod controller is too rigid and lack of flexibility when dealing with expansion and modification of Hexapod robot. Firstly, this project will determine the Hexapod robot movement by using gait analysis and analyze the optimum movement positioning of each servo motor. Then to control algorithm is incorporated into the processor program which is executed in FPGA. After that, this project will go through with designing 8-bit RISC processor. The obtain data will convert into a program code by using Xilinx software then it will implement into FPGA chip. The implementation of algorithms in soft-core processor offered better synchronization between the entire servomotor movements. A programming method of the soft-core is exactly the same with the conventional processor although it offered flexibility in extending the processor architecture to accommodate new input and output or other features. The significant implication of this project by combining the best of both worlds between microcontroller advantages in executing an instruction sequence efficiently and reconfigure features in FPGA.

ABSTRAK

Projek ini memberi tumpuan kepada rekabentuk dan pelaksanaan pemproses lembut teras dalam FPGA untuk mengawal hexapod robot. Dalam banyak aplikasi, pemproses lembut-teras menyediakan beberapa kelebihan pada rekaan pemproses seperti mengurangkan kos, fleksibiliti, platform bebas dan imuniti yang lebih besar kepada ketinggalan dari teknologi, tetapi sebab utama projek ini adalah pemproses lembut teras dalam FPGA akan menyediakan pilihan dalam mengubah suai susun atur I / O dan seni bina dalaman tanpa menggantikan papan mikropengawal, kerana pengawal mikro konvensional dalam pengawal hexapod terlalu sukar dan kekurangan fleksibiliti apabila berurusan dengan penambah baikan dan pengubahsuaian hexapod robot. Pertama, projek ini bermula dengan menentukan bagaimana robot hexapod ini akan bergerak, dengan menggunakan analisis gaya berjalan, gaya berjalan hexapod itu dikenalpasti dan dianalisa bagi menentukan pergerakan yang optimum dan kedudukan setiap motor servo. Kemudian untuk mengawal algoritma digabungkan untuk program pemproses yang dilaksanakan dalam FPGA. Selepas itu, projek ini akan melalui dengan mereka bentuk 8-bit RISC pemproses. Data yang telah diperolehi akan ditukar kepada kod program dengan menggunakan perisian Xilinx maka ia akan dimasukkan ke dalam cip FPGA. Pelaksanaan algoritma dalam pemproses lembut-teras menawarkan penyegerakan yang lebih baik antara keseluruhan pergerakan motor servo. Kaedah pengaturcaraan lembut-teras adalah sama dengan pemproses konvensional walaupun ia menawarkan fleksibiliti dalam melanjutkan seni bina pemproses untuk menampung input baru dan output atau ciri-ciri lain. Implikasi di dalam projek ini dengan menggabungkan yang terbaik daripada kedua-dua dunia antara kelebihan pengawal mikro dalam melaksanakan arahan urutan dengan cekap dan menyusun semula ciri-ciri dalam FPGA.

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ABBREVIATIONS

Table 1: table of Abbreviations

TITLE	MEANING
FPGA	Field Programming Gate Array
HDL	Hardware Description Language
CPU	Central Processing Unit
PLD	Programmable Logic Device
ASIC	Application Specific Integrated Circuit
SoPc	System on a Programmable Chip Builder
RISC	Reduce Instruction Set Computing
ROM	Random Access Memory
ALU	Arithmetic Logic Unit
JTAG	Joint Test Action Group
SRAM	Static Random Access Memory
USB	Universal Serial Bus
PWM	Pulse width Modulation
FSM	Finite State Machine

CHAPTER I

INTRODUCTION

1.1 Project Summary

A soft-core processor is a hardware description language (HDL) model of a specific processor (CPU) that can be customized for a given application and synthesized for FPGA target. In many applications, soft-core processors provide several advantages over custom designed processors such as reduced cost. Because this soft-core processor no need to going through the fabrication process, means, this soft-core processor not using special and expensive machinery to produce this type of processor at all. Because of this soft-core processor is fully design in Verilog code, this soft-core processor give more flexibility in terms of expending the system. Soft-core processor is platform independence and greater immunity to obsolescence.

This project will design and implement a Hexapod controller using a soft-core processor in FPGA platform, because the conventional Hexapod controllers use discrete microcontroller. So then there is no room for system expansion in order for it to be upgraded and modified. As example, in future if this system need to used more servo motor or need to used a sensors, designer only need to add some line of code in the Verilog code to make the soft-core processor is suitable with the new system. By the implementation of a soft-core processor in reconfigurable platforms such as FPGA, it will provide an option in modifying the I/O layout and the internal architecture without replacing the microcontroller board.

This project will also analyze and establish Hexapod movement mechanism using gait analysis. Gait analysis is the systematic study of animal locomotion, more specific as a study of human motion, using the eye and the brain of observers, augmented by instrumentation for measuring body movements, body mechanics, and the activity of the muscles. Gait analysis is used to assess, plan, and treat individuals with conditions affecting their ability to walk. It is also commonly used in sports biomechanics to help athletes run more efficiently and to identify posture-related or movement-related problems in people with injuries.

By developing a Hexapod controller based on soft core processor whereby the Hexapod's gait algorithm is programmed in the processor core and will be implemented in a Spartan-6 FPGA chip with the multiple I/O interface, the system will able to control all the 18 servo motors with 3 servos are allocated for each leg. The Hexapod is also capable to perform basic movement such as stand up, move forward and backward on a flat surface.

At the end of this project the microprocessor in FPGA will work smoothly with zero error and we can get a precise movement of control for all servo motors.

1.1.1 **Project introduction**

This project will design a soft-core processor that will implement in FPGA platform to controlling the movement of hexapod robot. Besides that this project also create a complex movement of the hexapod robot using the gait analysis.

This hexapod robot will perform a tripod gait movement. The tripod gait movement involved a multiple of servo motor movement in a single step, this tripod gait movements give a challenge how to organize the leg of hexapod robot move smoothly and precise.

In many applications, soft-core processors provide several advantages over custom designed processors such as reduced cost, flexibility, platform independence and greater immunity to obsolescence.

After succeeding implement the soft-core in FPGA, this project will use a single chip system (FPGA) to control all the servomotors in the movement of the

Hexapod. So the servo motors can give natural and precise movements and it will provide an option in modifying the I/O layout and the internal architecture without replacing the microcontroller board.

1.2 Introduction

Since their emergence in the mid-1980s, Field Programmable Gate Arrays (FPGAs) have become a popular choice for prototyping and production of products in small to moderate quantities. An FPGA is a special kind of Programmable Logic Device (PLD) that allows implementation of general digital circuits, limited only by the circuit size. The circuit to be implemented is defined by programming the device. Over the years, the capabilities of FPGA devices have grown to the level where a complete multiprocessor system can fit on a single device.

A soft-core processor is a microprocessor fully described in software, usually in an HDL, which can be synthesized in programmable hardware, such as FPGAs. A soft-core processor targeting FPGAs is flexible because its parameters can be changed at anytime by reprogramming the device. Traditionally, systems have been built using general-purpose processors implemented as Application Specific Integrated Circuits (ASIC), placed on printed circuit boards that may have included FPGAs if flexible user logic was required. Using soft-core processors, such systems can be integrated on a single FPGA chip, assuming that the soft-core processor provides adequate performance. Recently, two commercial soft-core processors have become available: Nios from Altera Corporation, and MicroBlaze from Xilinx Inc

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Several research projects have been carried out using the Hexapod robots as main platform is to test and verify various control algorithms. Most of these projects use the microcontroller as the brain of their system. The type of microcontrollers used are another-RISC architecture [1, 2], and Motorola microcontroller (MC9S12E64) [3]. There is also a controller that has been developed based on HDL and advanced analogue and mixed-signal (AMS) in which the simulation results are carried out based architecture 68HC12 microcontroller [4].

Hexapod robotic system implementation recently will use the FPGA platform. The FPGA is used to integrate the various modules in the Hexapod escort FPGA fabric [5] and to implement real-time algorithm escort [6]. The FPGA also performed as a processing medium to the main guardian of the Hexapod system that included cruise function [7].

On the mode of operation, the movement of some kind which is used in robot Hexapod, which is the tripod gait, gait and gait wave ripples. Based on some research Tripod gaits preferred because it is more stable and better performance on Hexapod robot [8, 9]. Tripod gait is essentially a mechanism in which the Hexapod legs operated as two tripods. In every movement, just three feet Hexapod that reaching the surface and another of leg Hexapod use to refuse to move forward.

2.2 Soft-core processor

Soft-core processors on field-programmable gate arrays (FPGAs) are an increasingly popular software implementation option in embedded computing systems. A soft-core FPGA processor is a synthesizable processor mapped onto the FPGA fabric, in contrast to a hard-core processor that is laid out next to the FPGA fabric. FPGA vendors tailor synthesizable processors, such as the Xilinx MicroBlaze or the Altera Nios, for FPGA implementation, resulting in processors having less size and performance overhead than a general synthesizable processor mapped to an FPGA [12] [13].

Soft-core, as well as hard-core processors on FPGAs enable reductions in system device counts by co-existing with custom processing circuits and glue logic on a single device. Soft-core processors possess an additional advantage of being realizable on general-purpose FPGA devices, with those devices typically being lower cost than devices with hard cores due to mass production and hence economy of scale

2.2.1 Why design with a soft-core

There are many reasons to choose a soft-core processor for other processing. The first reason is the processor type provides a large amount of flexibility through the configurable nature of the FPGA.

In the process of developing appropriate products, all requirements are gathered and set before the design of the project ever started. By engineers want this to happen, this seldom happens. Requirements often change during the course of the design and, in most cases, the need increased. In addition, the requirements are still being defined in the research and development situations.

Using soft-core processors can reduce a lot of the issues posed by the changing needs that could affect the project if using discrete microprocessor solutions. A soft-core processor solution will prevent design teams from a limited to a specific set of peripherals that may no longer fit the application requirements change or new features that are required.

Soft-core processors allow designers to add or reduce hardware from SoPC easily. In many toolsets, add and configure peripherals are usually done in a few short steps. Not only a simple addition of peripherals can be done, but there are a variety of peripherals are available from vendors

List of equipment, including memory controllers, timers, counter, blocks GPIO, UARTs (Universal Asynchronous Receiver Transmitter), and interconnects such as PCI, RapidlO, and HyperTransport. This list is constantly growing, giving designers a lot of options to build a SoPC. Peripheral and soft-core processors are designed in HDL (Hardware Description Language), allowing further customization of the system to be carried out.

2.3 Gait analysis

Gait analysis is the systematic study of animal locomotion, more specific as a study of human motion, using the eye and the brain of observers, augmented by instrumentation for measuring body movements, body mechanics, and the activity of the muscles. Gait analysis is used to assess, plan, and treat individuals with condition affecting their ability to walk. It is also commonly used in sports biomechanics to help athletes run more efficiently and to identify posture-related or movement-related problems in people with injuries.

This refers to the mechanism responsible for controlling leg step transitions (stance and swing) to assure that the Hexapod robot will not tumble. Most approaches try to replicate known insect gaits. However, other approaches have been used to find stable gaits. For instance, by running genetic algorithms or optimizing energy cost function. Basically the movement of the Hexapod is liked human prone and try to move forward or backward.

There is an example of Hexapod locomotion which is:

- Tripod.
- Crab.
- Pentapod

2.3.1 **Tripod gait**

Inspired by the insect world, Hexapods (six legged robots) provide an inherently stable platform that can be both easy to implement and efficient in operation. The overall stability of the Hexapod comes from its ability to establish a gait (walking pattern) in which at least three legs are on the ground at any time. The three legs will form a tripod with properties similar to a camera tripod or a three-legged stool - the robot will be stable as long as its centre of gravity falls within the support zone defined by the feet that are currently planted.

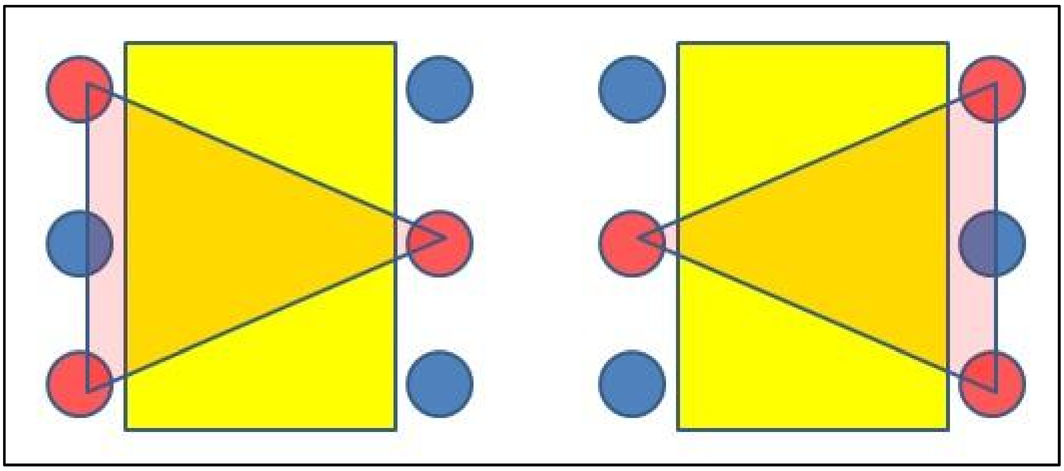

Figure 1: Tripod gait

The most basic Hexapod walking pattern is called tripod gait. In this gait, the six legs are treated in two groups of three. Either group of three is a tripod formed by the front and rear legs on one side, and the middle leg of the opposite side. The three component legs of each tripod are moved as a unit. As three tripods are lifted, the other three tripods push forward. In this gait, it can be helpful to think of each tripod as a foot and compare it to your own bipedal walking where as one foot is lifted the other foot pushes forward.

2.3.2 Crab

In this gait, the six legs also treated in two groups of three. Either group of three is a tripod formed by the front and rear legs on one side, and the middle leg of the opposite side. The three component legs of each tripod are moved as a unit. But for this gait, the movement is in a different way which is it going to the right side or left side. Just like how the crabs were moving. As one tripod is lifted, the other tripod pushes left or right.

2.3.3 Pentapod

In this gait, it just moves one leg at the time. For example, leg “A” move forward while the other leg waits for their turn to move. The stability of this kind of locomotion is still at the highest level because when the only one leg is lifted, there are five more legs are still standing on the ground.

CHAPTER III

METHODOLOGY

3.1 Project overview

The initial step to determine the hexapod robot movements is by using gait analysis so that the movement is using the most suitable gait pattern. Then this project will go through with 8-bit RISC processor design. All the data collected, it will be transformed to the Verilog code. It will implement to the FPGA chip. If any errors occur, the Verilog code will redesign the 8-bit RISC processor design, if this project running smoothly, the whole system will be analyzed if any part can be improved.

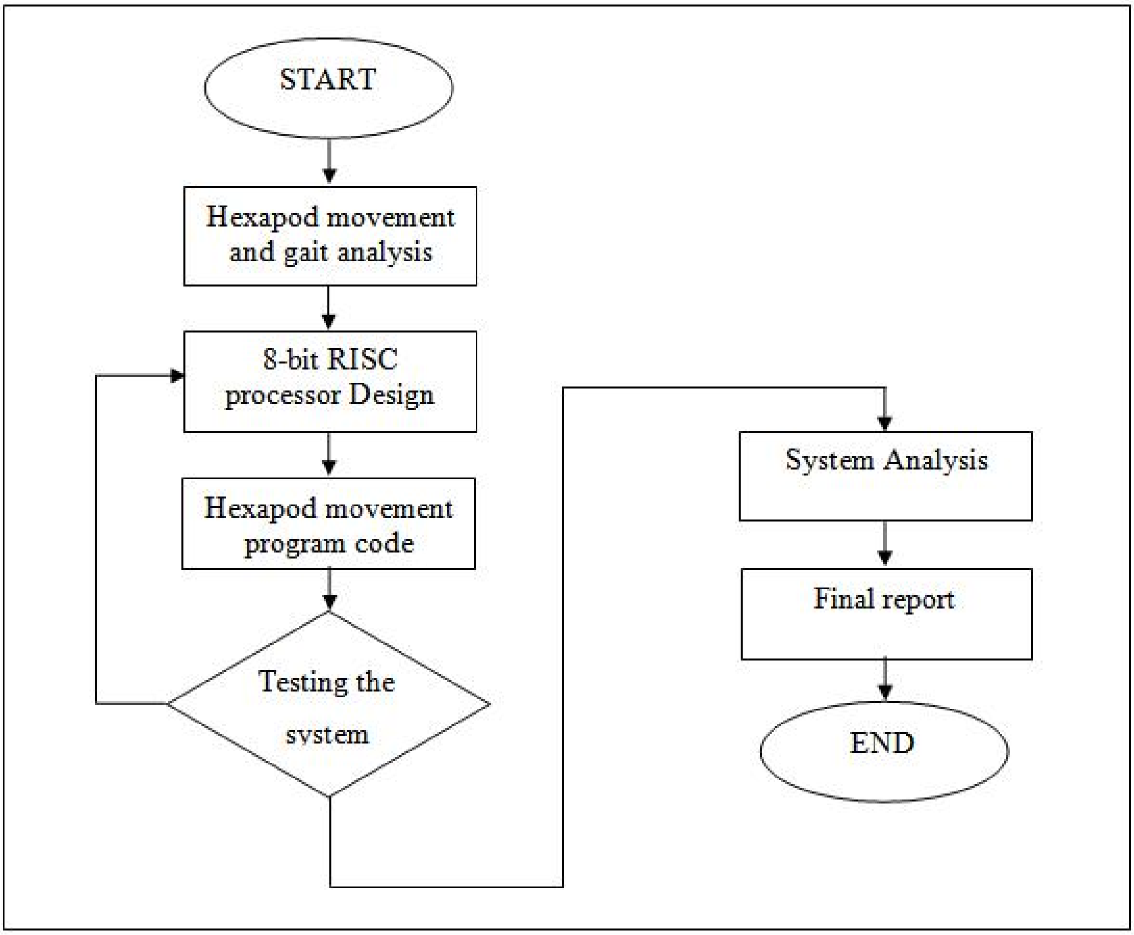

Figure 2: Flow chart of this project

3.1.1 Gait analysis

This robot has six legs, which were labelled as leg A, leg B, Leg C, leg D, leg E and leg F. And each leg has 3 servo motors that have been labelled to as the motor 1, motor 2 and motor 3.

At the beginning, this robot will be in the contract, or in the star position. The first movement of this robot to walk is to alienate all the legs to form a tripod formation, to mindfully stretches, motor 1 and motor 2 on all legs need to move. After mindfully stretches, leg A, C, D and F only move using motor 3 on each leg. Next, the motor 1 and motor 2 on each leg will move to allow the robot to stand as shown in Figure 3.

This robot uses the tripod gait to walk where the legs are affected in a triangular formation. So, the first movement to step is to use the motor 1 and motor 2