FPGA - BASED ARDUINO ARCHITECTURE IMPLEMENTATION

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor Degree in Electronic Engineering (Computer Engineering)

Faculty of Electronics & Computer Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2016

UNIVERSTI TEKNIKAL MALAYSIA MELAKA

FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN

PROJEK SARJANA MUDA II

Tajuk Projek : FPGA – BASED ARDUINO ARCHITECTURE IMPLEMENTATION

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Date : 16TH JUNE 2016

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Signature : .....

Supervisor's Name : EN. SANI IRWAN BIN SALIM

Date : 16TH JUNE 2016

To my beloved father and mother:

Your prayers keep me moving forward

Teachers

Fill my heart with the truth and knowledge

Beloved friends

Make my world happens

Every Muslim

May Allah bless you all here and hereafter

-Al-Fatihah-

ACKNOWLEDGEMENT

I am grateful to God for the mercy and blessing were given to me to fulfill my Final Year Project, "FPGA – Based Arduino Architecture Implementation."

In preparing this project, I would like to express my gratitude to my advisor Mr. Sani Irwan Bin Md Salim, for his constant support, guidance and valuable advice for the completion of this work and my graduate studies.

My sincere appreciation also goes to my family especially my parents who have morally and financially supported me from the beginning of my studies. Warmest regards to them for their seamless caring encouragement and moral support that has made this journey possible.

Last but not the least, I would like to thank my family: parents, brothers, and sisters for supporting me spiritually throughout writing this thesis and my life in general.

Finally, I would like to thanks to all people that help to fulfill this final year project. Thank you very much.

ABSTRACT

Since the past decade, Arduino has become popular and has been used in thousands of different projects and applications. The Arduino software is easy-to-use for beginners, yet flexible enough for advanced users. Having a soft-core processor which is compatible with the Arduino system would offer full customization on the system architecture. The purpose of this project is to implement Arduino processor core on FPGA. This project is about Arduino compatible soft processor integrate into the Arduino IDE. The Arduino IDE runs it sketches on the FPGA in the beginning and diversify into making VHDL Hardware Descriptive Language (HDL) peripherals for the soft processor. The project is addressing the limitations in the existing of the microcontroller. The beauty of the FPGA is it can become anything as in this project which is FPGA to be Arduino compatible board. This can prove that FPGA is very flexible and fast platform so virtually there is no limits in prototyping. Anything else including UART, PWM, Timers, interrupts are working fine when using this processor. The soft processor can be customized to have more I/Os or more peripherals like more PWM channels. This project shows the capability of adding extra new UART port that can be completely operational compared single UART port in conventional Arduino board. Data transfer test has been conducted successfully for both UART ports in the modified Arduino architecture. Even though the architecture is transformed, but it still used the same Arduino's standard software.

ABSTRAK

Sejak beberapa dekad yang lalu, Arduino telah popular dan telah digunakan dalam beribu-ribu projek dan aplikasi yang berbeza. Perisian Arduino mudah digunakan terutamanya bagi yang baru belajar, tetapi cukup fleksibel untuk pengguna yang sudah lama mengenali perisian tersebut. Dengan mempunyai pemproses lembut teras yang serasi dengan sistem Arduino itu akan menawarkan penyesuaian penuh pada seni bina sistem. Tujuan projek ini adalah untuk melaksanakan Arduino pemproses teras pada FPGA. Projek ini adalah mengenai Arduino pemproses lembut serasi menyepadukan ke dalam Arduino IDE. Arduino IDE pada mulanya membuat lakaran pada FPGA dan mempelbagaikan ke dalam membuat VHDL Hardware Description Language (HDL) peripheral untuk pemproses lembut. Projek ini dapat menangani batasan dalam kewujudan mikropengawalan. Mikropengawal yang sedia ada mempunyai had masalah dan perlu diganti dengan teknologi baru. Keunikan FPGA boleh dipelbagaikan seperti projek ini yang mana FPGA serasi dengan papan Arduino. Ini dapat dibuktikan bahawa, FPGA adalah sangat fleksibel dan tiada batasan platform dalam prototaip. UART, PWM, Timer dan pengganggu berjalan dengan lancar dengan adanya pemproses tersebut. Pemproses tersebut boleh disesuaikan untuk mempunyai lebih banyak I/Os atau lebih persisian seperti lebih saluran PWM. Projek ini menunjukkan keupayaan untuk menambah tambahan port UART baru yang boleh benar-benar beroperasi berbanding pelabuhan UART tunggal di papan Arduino konvensional. Ujian pemindahan data telah dijalankan dengan jayanya untuk kedua-dua pelabuhan UART dalam seni bina Arduino yang diubah suai. Walaupun seni bina itu berubah, tetapi ia masih menggunakan perisian standard Arduino yang sama.

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LIST OF ABBREVIATION

FPGA	-	Field Programmable Gate Array
VHDL	-	Very High Speed Integrated Circuit Hardware Description Language
IDE	-	Integrated Development Environment
PWM	-	Pulse Width Modulation
DSP	-	Digital Signal Processor
ASIC	-	Application-Specific Integrated Circuit
GPIO	-	General- purpose input/output
SPI	-	Serial Peripheral Interface

CHAPTER 1

INTRODUCTION

This chapter is about the implementation Arduino core processor on FPGA. This thesis will discuss the introduction, problem statement, objectives, and scope of the project. The end of this chapter will list the thesis outline.

1.1 Project Overview

In the world of electronics and digital circuitry, the term microcontroller is very widely used. Almost every single device that is meant to connect and interact with a computer has an embedded microcontroller inside to facilitate the communication. The structure of a microcontroller is comparable to a simple computer placed on a single chip with all of the necessary components like memory and timers embedded inside. It is programmed to do some simple tasks for other hardware.

This chapter contains background information regarding the modern FPGA architectures as well as to implement Arduino processor core on FPGA. It highlights the current Arduino-based framework are specially crafted to its specific board model. For case, Arduino UNO is for learner level while Arduino Mega is for development level. The framework arrangements are confined inside of the board determination consequently restricting future extension ability on the system. Having a sensitive processor which is flawless with the Arduino system would offer full customization

on the structure basic arranging confinements in the current of a microcontroller which is it has a restriction issue and should have been supplanted with new innovation which is FPGA.

1.2 Problem Statement

The current Arduino-based system is custom-made to its particular board model. For example, Arduino UNO is for beginner level while Arduino Mega is for advanced level. The system configurations are restricted within the board specification hence limiting future expansion capability on the system.

1.3 Objectives of Project

The objective of this project is to develop Arduino-based architecture on FPGA platform.

1.4 Scope of Project

The job scope of this project is to implement Arduino processor core on FPGA. The hardware architecture is described using VHDL language. Xilinx ISE is used as a software and Spartan 6 Papilio One 500k FPGA board is utilized as the hardware programming platform in this project.

1.5 Chapter Review

Chapter 1 provides overall concept regarding the on-going project. It covers the introduction where the public can access and get to know the implementation Arduino processor core on FPGA. Aside from that, project objectives, problem

statement, scope as well as chapter review are available within chapter 1 of this exposition. Thus, readers are well informed on the confinement about this research.

Chapter 2 comprises of literature review based on Arduino processor on FPGA. The corresponding of literature review will refine and zoom deeper into the concept which is closely related to my project through figure and diagram.

Chapter 3 presented the methodology of the analyzing and classification process of Arduino processor on FPGA. Flow chart of the project will be presented in this chapter with the description as well.

In chapter 4, all results from the project are included. The results are majority focus on software using Xilinx ISE and Arduino IDE is shown. The file also will test at FPGA processor to verify the file is creating well. The result will be presented in coding in this chapter.

Chapter 5 will present the conclusion of this project after all the theoretical, analysis and coding result is achieved. The future work also involved in this chapter.

CHAPTER II

LITERATURE REVIEW

This chapter summarizes the literature review on theoretical concepts applied in this project. It contains the information that the project required in order to develop and complete the entire project.

2.1 Introduction

2.1.1 Introduction to FPGA

Field Programmable Gate Arrays (FPGA) are reconfigurable hardware devices that can be reprogrammed to implement different combinational and sequential logic created with the aim of prototyping digital circuits, as they offer flexibility and speed. In recent years, the advance in technology have permitted to construct FPGAs with considerable large amounts of processing power and memory storage, and as so they have been applied in several domains (telecommunications, robotics, pattern recognition tasks, infrastructure monitoring, etc.) [13], [16], [17], [18]. It designed the flexibility to create a wide array of logic circuits at a low cost because it is not necessary to manufacture a new custom made integrated circuit each time.

2.1.2 Introduction to Arduino

Arduino is an open-source prototyping platform based on easy-to-use hardware and software. Arduino boards are able to read inputs for example light on a sensor, a finger on a button, or a Twitter message and turn it into an output with activated a motor, turning on an LED, publishing something online. The main advantage of the Arduino is, directly load the programs into the device without the need of a hardware programmer to burn the program. This is done because of the presence of the 0.5KB of the boot loader, that allows the program to be dumped into the circuit. By sending a set of instructions to the microcontroller on the board, the board will run their program smoothly. The Arduino software that usually used is Arduino programming language (based on Wiring), and the Arduino Software (IDE), based on Processing.

2.1.3 FPGA Architecture

Field Programmable Gate Arrays (FPGAs) are pre-fabricated silicon devices that can be electrically programmed in the field to become almost any kind of digital circuit or system. The general FPGA architecture consists of three types of modules. They are I/O blocks or Pads, Switch Matrix/ Interconnection Wires and Configurable logic blocks (CLB). The basic FPGA architecture has two-dimensional arrays of logic blocks with a means for a user to arrange the interconnection between the logic blocks. The functions of an FPGA architecture module are discussed and the FPGA architecture in Figure 1.1 is shown as below:

- CLB (Configurable Logic Block) includes digital logic, inputs, outputs. It implements the user logic.
- Interconnects provide direction between the logic blocks to implement the user logic.
- Depending on the logic, switch matrix provides switching between interconnects.
- I/O Pads used for the outside world to communicate with different applications.

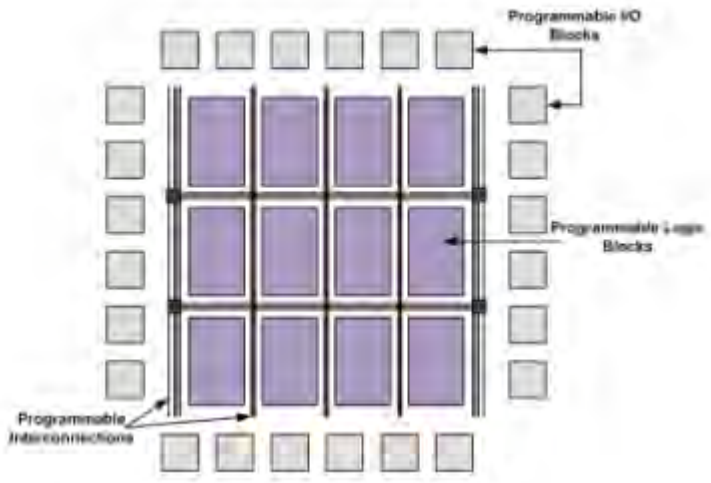

Figure 1.1 : FPGA Architecture

2.1.4 Arduino Architecture

Fundamentally, the processor of the Arduino board utilizes the Harvard engineering where the project code and program information have separate memory. It consists of two memories such as program memory and data memory. Wherein the data is stored in data memory and the code is stored in the flash program memory. Figure 1.2 below shows the architecture of Arduino.

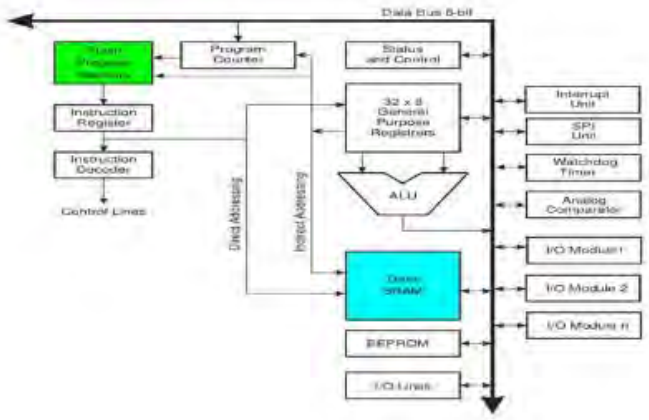

Figure 1.2: Arduino Architecture

2.1.5 Differences between FPGA and microcontroller

Almost every single device that is meant to connect and interact with a computer has an embedded microcontroller inside to facilitate the communication. The main and the most significant difference between the microcontroller and the FPGA is the structure of a microcontroller is comparable to a simple computer placed on a single chip with all of the necessary components like memory and timers embedded inside. It is programmed to do some simple tasks for other hardware. A Field Programmable Gate Array or FPGA is an integrated circuit that could contain millions of logic gates that can be electrically configured to perform a certain task.

FPGA does not have a fixed hardware structure, on the opposing, it is programmable according to user applications. However, processors have a fixed hardware structure. It means that all the transistors memory, peripheral structures, and the connections are constant. The very basic nature of FPGAs allows it to be more flexible than most microcontrollers. The term field programmable already tells that the whole FPGA device can be reprogrammed to do any logic task that can be fitted into the number of gates that it has. Microcontrollers already have their own circuitry and instruction set that the programmer must follow in order to write code for that microcontroller which restricts it to certain tasks.

Be that as it may, programming of FPGAs takes a more extended time to do a particular errand contrasted with the system a microcontroller. The developer needs to keep in touch with all the codes for the FPGA however for the microcontroller, the client can purchase programming bundles to program the microcontroller generally rapidly.

2.2 Related Project

Through the review of some projects and studies, there are three journals found to be related to this project. These journals have been analyzed, summarized, and evaluated. The comparison between the related projects and this final year project have been listed.

2.2.1 Cloud Based Development Framework Using IOPT Petri Nets For Embedded Systems Teaching [1]

This journal is prepared by Luis Gomes and Aniko Costa from University Nova de Lisboa, Faculty Science Technology & UNINOVA, CTS, Portugal in the year 2014.

This project is about the implementation of IOPT Petri Nets model in digital system design course. The IOPT-Tools [10] framework is used to support a cloud-enabled design automation flow, including specification of system's behavior, state space based verification, and automatic code generation (C and VHDL) leading to implementation deployment into reconfigurable computing platforms (FPGA based boards and Arduino devices). There are two parts of selected systems that were used in this project, which is for hardware implementation language, VHDL is selected and for a software implementation, C language is used. Besides that, this project was used FPGA Spartan 3 XC3S200 and Arduino as Microcontroller platform.

2.2.2 A Low Cost Open Source High Frame-Rate-High Frequency Imaging System[2]

This journal is prepared by J.A.Brown, M.Leung, A.Bezanson and R.Adamson from Biomedical Engineering, Dalhousie University, Halifax, NS, Canada in the year 2013.

This project This anticipate is about the portrayal of minimal effort open source ways to deal with high recurrence ultrasound imaging framework. The framework is utilizing FPGA Virtex V Microcontroller stage Arduino Nano and Python as a language. The limitation preventing higher display frame rates is the serial calculations used to produce model images from the captured high-frequency data.

2.2.3 Implementation Of WSN Which Can Simultaneously Monitor Temperature Conditions And Control Robot For Positional Accuracy [3]

This journal is prepared by Sharul Agrawal from Department of Information Technology, Dharamsinh Desai University Nadiad, Gujarat, India and Ravi N. Prakash from Remote Handling & Robotics Development, Institute for plasma Research, Nr, Indira Bridge Gandhinagar, India in the year 2014.

This project is about Implementation of wireless sensor networks in remote handling environment by sending signals over far distances by using a mesh topology transfers the data wirelessly and also consumes low power. The system that used in this project is FPGA NI Starter Kit with Atmega328(Arduino) and micro-controller + XBee. While for software part, Arduino IDE software that utilizes C language is used. This project is developing a prototype of Wireless Sensor Network(WSN) by deploying one temperature node to another node for temperature monitoring.

Table 2.1: Comparison between the journals and this project

Title	Overview	System	Performance
Cloud Based Development Framework Using IOPT Petri Nets For Embedded Systems Teaching [1] *By Luis Gomes and Aniko Costa (2014)*	- Implementation of IOPT Petri Nets model in digital system design course.	- Using FPGA Spartan 3 XC3S200. - Language: VHDL and C - Arduino as microcontroller platform	- Provide a platform to integrate the concept of behavior modeling deployment of FPGA and Arduino.

Title	Overview	System	Performance
A Low Cost Open Source High Frame-Rate-High Frequency Imaging System[2] *By J.A.Brown, M.Leung, A.Bezanson, and R.Adamson (2013)*	- Description of low cost open source approach to high-frequency ultrasound imaging system.	- Using FPGA Virtex V. - Microcontroller platform-Arduino Nano - Language: Python language.	- The limitation preventing higher display frame rates is the serial calculations used to produced model images from the captured high-frequency data.
Implementation Of WSN Which Can Simultaneously Monitor Temperature Conditions And Control Robot For Positional Accuracy [3] *By Sharul Agrawal and Ravi N. Prakash (2014*	- The advantage of wireless sensor networks in remote handling environment by sending signals over far distances by using a mesh topology transfers the data wirelessly and also consumes low power.	- Using FPGA NI Starter kit. - Microcontroller platform: Arduino Atmega328 + XBee. - Using Arduino IDE software that utilizes C language.	- Develop a prototype of Wireless Sensor Network(WSN) by deploying one temperature node to another node for temperature monitoring.