FPGA-BASED IMPLEMENTATION OF ELECTRONIC ABACUS USING ALTERA DE2 BOARD

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For my beloved mother, my dearest wife and children.

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ABSTRACT

The development of electronic abacus is to integrate the use of abacus along with electronic devices which offers better visualisation of the abacus operations. The main focus of this application is to assist the primary school students' in validating a fundamental arithmetic operation by using an abacus. The electronic abacus is developed by integrating an abacus, abacus decoder module and FPGA-based processor. DE2 115 is chosen as the development module and VHDL as main programming language. The arithmetic algorithm developed for the electronic abacus is limited to the computational of whole numbers only. The electronic abacus is operational in two modes, display mode and arithmetic mode. In the display mode, the abacus beads position at column 1 until column 7 is displayed as numerical representation on the LCD screen. A computation of arithmetic operations with less than three operators are available in the arithmetic mode with the capability of displaying the negative numerical and infinite value. The implementation of integrating an abacus with electronic devices will hopefully contribute in the development of more lively and interesting teaching approach by using this ancient apparatus.

ABSTRAK

Penghasilan abakus elektronik yang menggabungkan abakus bersama peranti elektronik dapat menggambarkan operasi aritmetik abakus yang lebih jelas kepada penggunanya. Digunakan sebagai alat bantuan bagi pelajar sekolah di peringkat sekolah rendah dan sebagai pengesah operasi aritmetik bagi abakus. Abakus elektronik dihasilkan dengan menggabungkan abakus, modul pengekodan serta pemproses berasaskan FPGA. DE2 115 dipilih sebagai modul pembangunan dan VHDL sebagai bahasa pengaturcaraan utama. Algoritma aritmetik yang dibangunkan bagi abakus elektronik ini, bagaimanapun terhad kepada pengiraan untuk nombor bulat sahaja. Abakus elektronik beroperasi dalam dua mod, iaitu mod paparan dan mod aritmetik. Pada mod paparan, pengguna dapat melihat perwakilan nombor pada paparan LCD yang mewakili kedudukan manik abakus pada lajur pertama hingga lajur ke 7. Selain itu, pengiraan operasi aritmetik bagi kurang dari tiga pengoperasi boleh dilaksanakan dalam mod aritmetik dengan keupayaan paparan nilai negatif dan infiniti. Integrasi di antara peranti elektronik dengan abakus diharapkan dapat membangunkan penghasilan kaedah pembelajaran menggunakan abakus yang lebih menarik dan bertenaga.

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LIST OF SYMBOLS AND ABBREVIATIONS

Ω	-	Resistance
A.D	-	Anno Domini
ASCII	-	American Standard Code for Information Interchange
B.C	-	Before Christ
CMOS	-	Complementary Metal Oxide Semiconductor
DE2	-	Development and Education board version 2
FPGA	-	Field-programmable gate array
GPIO	-	General-purpose input/output
LCD	-	Liquid Crystal Display
I^2C	-	Inter-Integrated Circuit
RTL	-	Register Transfer Level
SDA	-	Serial Data
SCL	-	Serial Clock
TTL	-	Transistor-Transistor Logic
USB	-	Universal Serial Bus
V	-	Volt
VCC	-	Collector Supply Voltage
VDD	-	Drain Supply Voltage
VHDL	-	Very High Speed Integrated Circuit Hardware Description Language

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Arithmetic operation is a process of adding and subtracting numbers. The advancement of these operation produce multiplication and division operations. The invention of counting apparatus is major step in human civilisation and influenced by continuous development of these mathematical process. Abacus is a counting apparatus which undergo multiple evolutions, is believed to be initiated by the Babylonian, popularise in ancient Chinese and perfected by the Japanese. As automatic counting machine such as calculator become more common these day, the traditional counting machine such as abacus still plays an important role in the development of children intellectual. The uses of abacus in Malaysian early education, proves that this ancient counting machine is far from being forgotten. The fingers manipulation during operating of the abacus, develop a mental calculator for the users thus integrate active process on both side of the brain. Furthermore, the uses of abacus will boost up children mathematical confidence level thus preparing the younger generation to be more confident in facing the future challenges [1] and develop active attitude toward study [2].

1.2 Problem Statement

The practise of traditional abacus as brain stimuli has been acknowledge worldwide and proven to be an effective method in mathematical learning process. Learning a traditional abacus without the presence of a teacher is proven to be a hassle, as it requires different technique for different mathematical operation. This drawback has been acknowledged by the researcher, and the development of computerised module related to abacus usage for the young and old, has filled the gap. The virtual abacus or software based application thus provide better visualisation of operation and technique used, but missing out on the physical experience perspective.

The development of electronic abacus is an approach to validate the mathematical operation conducted by an abacus, without missing the physical experience of using it. It is design as additional apparatus which can be detached while not in use, thus preserving its authenticity. The electronic abacus algorithm can be developed using various programming language. The development of electronic abacus algorithm using VHDL programming language is chosen as its offers better digital design flexibility and synthesizable register transfer level (RTL), which later can be used to develop its specific function of integrated circuit. Furthermore, VHDL programming offers precision simulation for complex algorithm compared to other microprocessor simulations. The development of electronics abacus could promote a better understanding and active learning process in mathematical courses for kindergarten, schools' student as well as adult learners.

1.3 Objectives

Objective of this projects are as follows:

a) To develop an electronic abacus validator for the use of learning mathematical through arithmetic operation.
b) To develop a concise apparatus with detachable standard size abacus.
c) To evaluate the implementation of VHDL programming in DE2 thus validate electronic abacus application.

1.4 Project Scope

There are several scopes for this project as listed below.

a) The abacus used is a wooden standard size Japanese abacus which is commonly used as educational tools in primary schools.

b) The arithmetic operations are limited to fundamental operation such as addition, subtraction, multiplication, division and combination of two operators.

c) The decimal notation for multiplication and division is excluded as the reference of unit rod is varied for these operations.

d) Arithmetic operations can be conducted with two or three variables with various arithmetic combinations.

e) Arithmetic processes involved in division operation or combination of division operations, will produced a whole number result without the remainder.

f) The arithmetic process is limited to only whole numbers operations and capable of displaying numerical representation up until 10^7 (0 to 9999999).

1.5 The Organisation of Thesis

This thesis consists of five chapters:

Chapter 1: This chapter deals with the basic introduction of abacus, problem statement, objectives and project scope.

Chapter 2: This describe the history of abacus, the construction of abacus used, arithmetic operational technique and previously related works associated with this project.

Chapter 3: This chapter discussed the methodological aspect of the project. The planning of the project is demonstrated and the hardware design and configuration is discussed. Moreover, the software development method and implementation is explained.

Chapter 4: This chapter deals with the result and analysis obtained both from the experiment and simulation.

Chapter 5: The final chapter concludes the outcome of the project and few discussions regarding future work or recommendation to further improvement of the future design.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Abacus is a calculating apparatus used to perform various arithmetic calculations. The abacus evolution is influenced by the development of arithmetic operations and the use of various numeral notations. The modern day abacus has gone through various adaptation and developed to comply with the modern numeral notation, which is based upon Arabic numbering system. The development of electronic based abacus is a step forward in utilising this ancient apparatus alongside with an electronic device to promote more interesting and conducive mathematical learning process for the early education.

2.2 Abacus Historical Review

The abacus is generally defined as an ancient calculating tools which used in trade to solve arithmetic problems [3]. The first counting tablet was introduced in Sumer dated somewhere in period of 4000 B.C [4]. Abacus terminology originated from Arabic word of 'abq' which means dust or fine sand, later adapted to Latin word as abacus, which means the sand tray [5]. It reflects the uses of clay or wood tray filled with sands for writing symbol in the early age its usage. It eventually evolved into stone counting boards with parallel grooves and pebbles. Known as 'abax' or 'abakon' to the Greek, which defined as table or tablet. The last surviving of ancient counting board was discovered in Salamis Island on 1846, named the Salamis tablet. Believed to be used during Babylonians circa 300 B.C [5].

The Roman invented the first hand held abacus named calculus which later renamed as calculi, consists of parallel slits representing Roman numerical notations [5] [6]. The idea of dividing each slits into decimal position, give birth to the implementation of such characteristics in Chinese and Japanese abacus. Figure 2.1 and 2.2 illustrate the configurations of Salamis tablet and Roman Abacus.

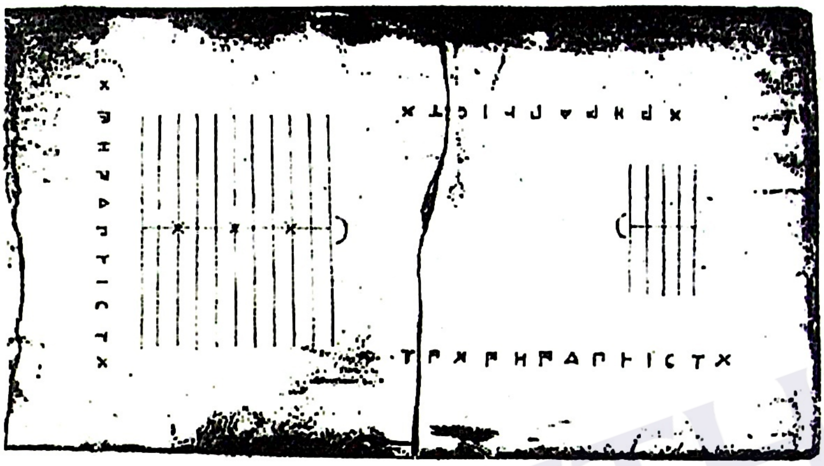

Figure 2.1: Salamis Tablet [6]

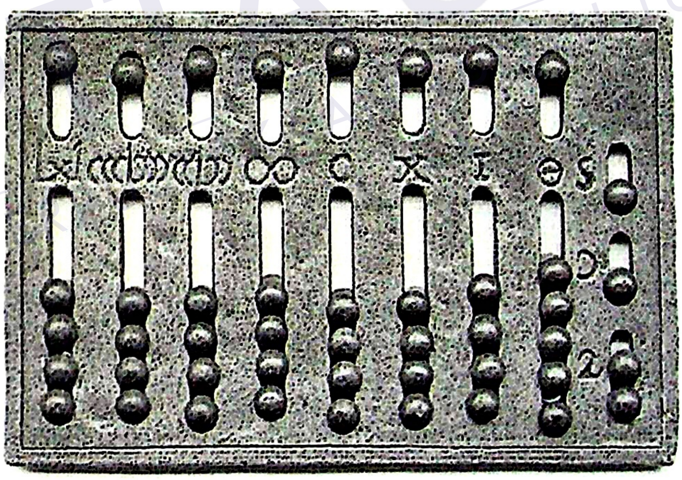

Figure 2.2: Replica of Roman Abacus [6]

In mid-century, the abacus is further evolved by introducing more counting columns and the replacement of pebbles to printed 'jeton'. Each 'jeton' is a representation of seven pebbles. At the end of 12th century, the design further evolved into nine vertical columns, with each 'jeton' representing one to nine digits [6]. The European version of abacus is further developed in 14th century, but the use of abacus became diminished after the counting with written numbers (arithmetic) gains it popularity.

The invention of Chinese abacus or 'suan-pan' dated back from the period of 1200 A.D [7] [8]. The configuration of Chinese abacus is illustrated in Figure 2.3. The Chinese abacus is built upon a frame construction of wood and metal reinforcement, consists of upper deck and lower deck. Each column represented by a rod, consists of two beads on the upper deck and five beads on the lower deck; such configuration is also known as 2/5 abacus [7] [8]. Each column is representing decimal points according to Arabic numerical notations. This configuration remains unchanged until 1850 where 1/5 abacus with a single bead in upper columns was introduced. Awarded as Fifth Invention of Ancient China, the abacus is able to conduct arithmetic operation such as addition, subtraction, multiplication and division; it also has the ability to perform square roots and cubic roots [9].

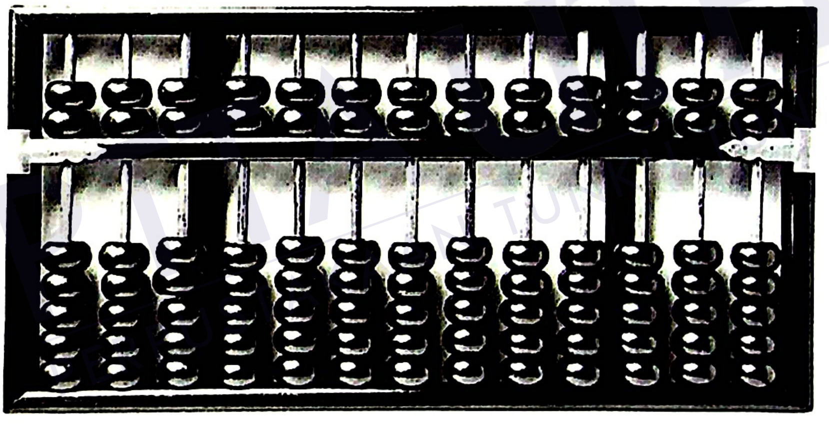

Figure 2.3: Chinese abacus (2/5 suan pan)

The wide application of abacus in ancient China, gain its worldwide impact. The invention of Japanese abacus in 16^{th} century is strongly influenced by 1/5 Chinese abacus. The present day soroban, or Japanese abacus consists only one bead on upper deck and four beads on the lower deck. This configuration remains unchanged since 1930. The 1/4 abacus configuration is the most suitable for decimal calculation, thus abandoned hexadecimal calculation applied by the Chinese abacus [10]. Mathematical operation perform by Japanese abacus does not limit the user of using only round numbers but also in decimal points, as well as negative numbers [4]. A modern day Japanese abacus is as depicted in Figure 2.4.

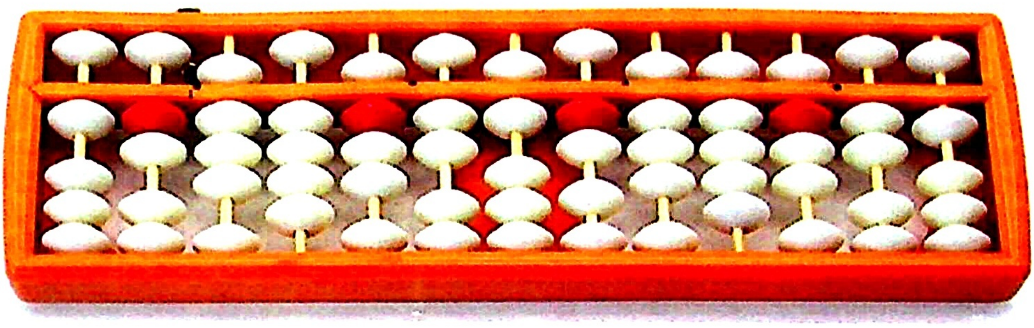

Figure 2.4: Japanese abacus (soroban)

Figure 2.5 illustrate the evolution of counting boards from the earliest of its existence until the present day. The development of counting boards in Western Europe is at a standstill since the introduction of Arabic numbering system [7]. The modern day abacus is constructed based on Japanese abacus as it is uses common Arabic numerical system, provide multiple variation of arithmetical operation and much preferred worldwide compared to traditional Chinese abacus.

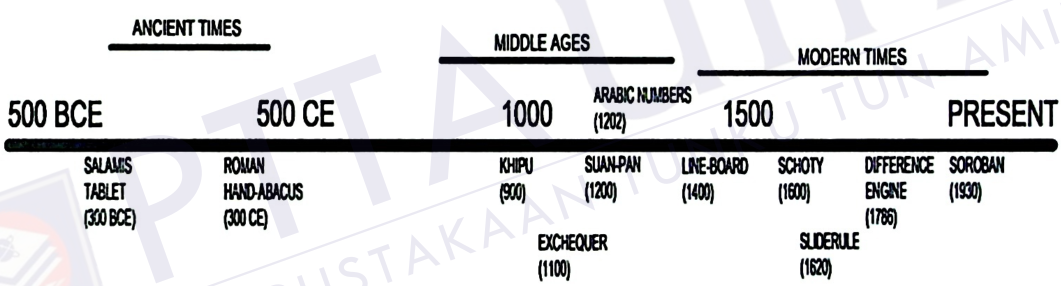

Figure 2.5: The evolution of counting devices [7]

2.3 Abacus Architecture

This section is dedicated to elaborate the fundamental notation and bead values. The application is focused on the Japanese abacus as it is the main instrument used in this project. Japanese abacus is constructed with a slider rod that hold five beads in each column. A horizontal separator divides a single bead on the upper deck which represent five points and four beads on the lower deck representing a single point for each beads. The four notations specified by a dot on the horizontal separator, indicated the thousandth, unit, thousands and millions decimal locations. The illustration in Figure 2.6 displays the common Japanese abacus constructions and it notifications.

Each columns configuration represents decimal numeral value, ranges from 0 to 9 according to its decimal position. Figure 2.7 shows the beads configuration with respect to equivalent decimal numbers. Calculations of round number shall begin at the second dot from the right. The initial value of 0 is achieved when no beads is touching the bar and value of beads are counted otherwise. The addition of value 5 and 1's concludes the possibilities of achieving numeral representation of 0 to 9. These principles are applied for all the columns, providing various possibilities of numeral representation.

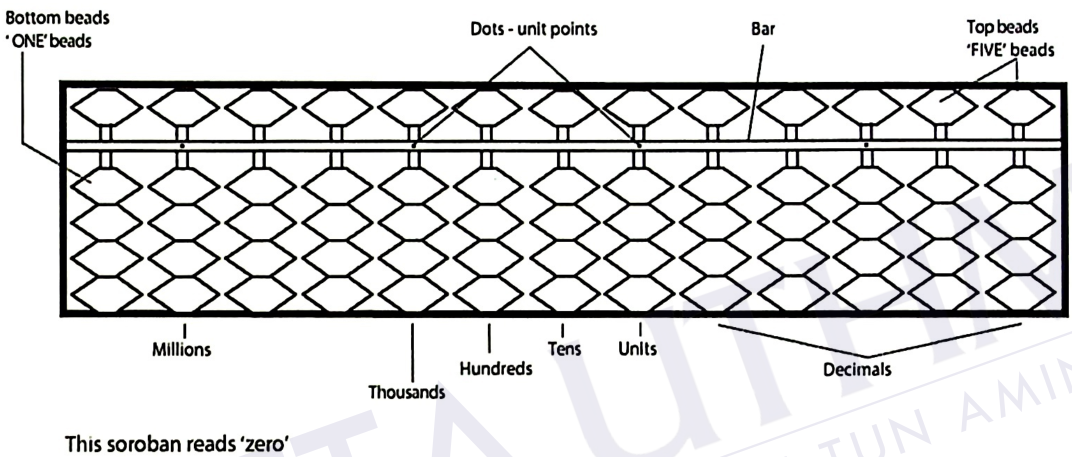

Figure 2.6: Japanese abacus construction and notations

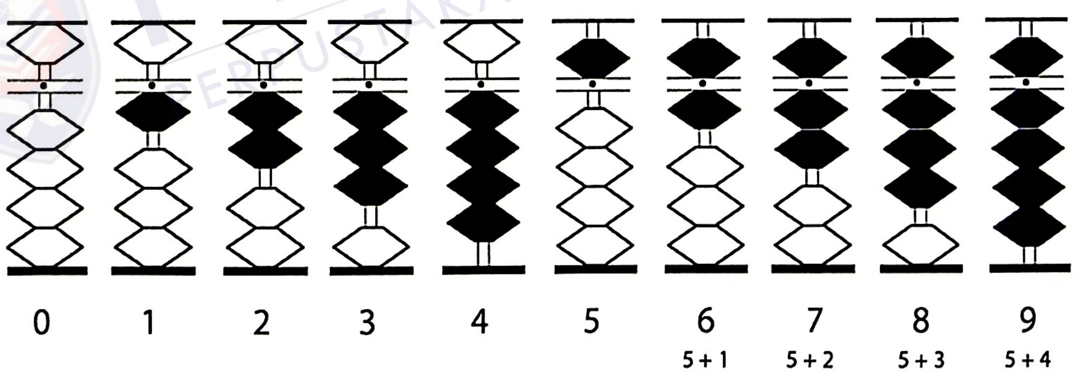

Figure 2.7: Japanese abacus beads position and numerical value

2.4 Abacus Arithmetic Operation

Abacus is able to emulate multiple arithmetic operations, the imminent discussion covers the fundamental arithmetic operations such as addition, subtraction, multiplication and division. The abacus does not compute the arithmetic functions like calculator, but providing the process of achieving the same goal as a counting machine. Each arithmetic operation requires different technique and will be discussed further.

The important rules of arithmetic operation using abacus is, to begin the process from left bead rods to the right and the use of complementary numbers of 5's or 10's. Each technique of complementary numbers is grouped into its total sum such as combination of 4 and 1 or 3 and 2 for complementary number of 5's. The rules is also applied for complementary of 10's which group into five possible combinations.

2.4.1 Addition

The following procedure perform an addition operation of 45.7 + 4.5. The method of complementary numbers is demonstrated.

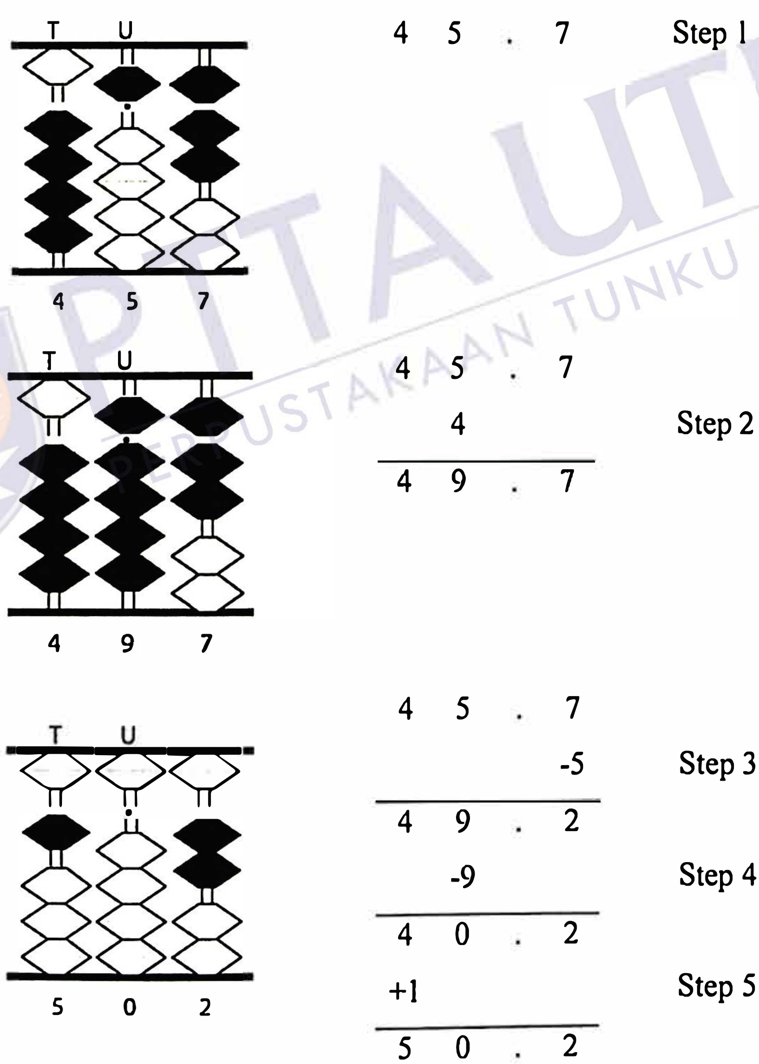

Figure 2.8: Additional Operation

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