THE DESIGN OF 16 X 1 ARRAY PHOTON COUNTING CIRCUIT WITH BRENT-KUNG ADDER OPTIMZATION

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DEDICATION

This thesis is dedicated to my father Ndottiwa Ngari, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother Adji Abba, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Farming involves sequence and processes of cultivating crops; among others are bush clearing, irrigation, and soil testing. The soil testing carried out manually by dissolving chemical reagent to form a color, then compared with a color chart is time consuming and error prone without quantitative value. Subsequent systems comprise spectrophotometer, general packet radio service (GPRS), artificial neural network (ANN), and raspberry pi based are expensive and slow. Another system has been developed based on field programmable gate array (FPGA) with capability to test one sample at a time. FPGA supports parallel computing, but it depends on the program written to synthesize the hardware. To tap this advantage, this study developed a design of FPGA based photon counting system, using 16 bits parallel adder (Brent Kung) algorithm. The developed system comprises 16 bits buffer, 16 bits adder, 16 bits parallel input serial output (PISO), and the clock divider circuit. The incoming signal stored in buffer and passed to parallel adder. The parallel adder passes the result to PISO and the clock divider was used to control the counting. The main advantage of the method is speed, the algorithm allows parallel computation, such that, it will be easily implemented in low cost FPGA module. The speed of the adder was achieved by making FPGA operate in parallel mode. To test the effectiveness of the proposed method, Verilog hardware description language was used to synthesize through Vivado suite by Xilinx and simulated under different condition by changing the samples signal with various degree of frequency. It was further verified with Synopsys. The superiority of the proposed method over the conventional is high frequency of 625 MHz in FPGA, 1190 MHz for Brent Kung integrated circuit (IC) and 1639 MHz for two stage pipeline Brent Kung integrated circuit with low power of 2 mW in gate levels. It is envisioning that the proposed method will be very useful in the implementation of high performance, low cost for not only soil nutrient measurement, but also for transforming other serial system to parallel system.

ABSTRAK

Perladangan melibatkan urutan dan proses-proses menanam tanaman; antara prosesnya adalah membersihkan belukar, pengairan, dan pengujian tanah. Pengujian tanah yang dijalankan secara manual dengan melarutkan reagen kimia untuk menghasilkan warna, yang kemudian dibandingkan dengan carta warna adalah memakan masa dan cenderung berlaku ralat tanpa nilai kuantitatif. Sistem-sistem seterusnya terdiri daripada spektrofotometer, perkhidmatan radio paket umum (GPRS), rangkaian neural tiruan (ANN), dan pangkalan Pi raspberi adalah mahal dan lambat. Sistem lain telah dibina berdasarkan tatasusunan get boleh atur lapangan (FPGA) dengan keupayaan untuk menguji satu sampel pada satu masa. FGPA menyokong pengkomputeran selari tetapi ia bergantung kepada program yang ditulis untuk membina perkakasan. Bagi mencungkil kelebihannya, kajian ini membangunkan reka bentuk sistem pengukuran foton berasaskan FGPA menggunakan algoritma penambah selari 16 bit (Brent Kung). Sistem yang dibangunkan mengandungi penimbal 16 bit, penambah 16 bit, output bersiri input selari (PISO) 16 bit, dan litar pembahagi jam. Isyarat masuk disimpan dalam penimbal dipindahkan ke penambah selari. Penambah selari memindahkan keputusan ke PISO dan pembahagi jam digunakan untuk mengawal kiraan. Kelebihan utama kaedah ini ialah kelajuan, algoritma membenarkan pengkomputeran selari, dengan itu ia mudah dilaksanakan dalam modul FPGA berkos rendah. Kelajuan penambah dicapai dengan membuatkan FGPA beroperasi dalam mod selari. Bagi menguji keberkesanan kaedah yang dicadangkan, bahasa pemerian perkakas Verilog digunakan untuk mensintesis melalui suit Vivado oleh Xilinx dan disimulasikan di bawah beberapa keadaan dengan mengubah isyarat sampel dengan pelbagai darjah frekuensi. Ia kemudian disahkan dengan Synopsys. Keunggulan kaedah dicadangkan berbanding kaedah konvensional ialah frekuensi tinggi pada 625 MHz dalam FPGA dan 1190 MHz bagi litar bersepadu (IC) Brent Kung dan 1639 MHz bagi talian paip dua peringkat litar bersepadu (IC) Brent Kung dengan kuasa serendah 2 mW pada tahap get. Kaedah dicadangkan ini dijangka menjadi sangat berguna dalam pelaksanaan bukan hanya pengukuran nutrien tanah prestasi tinggi dan kos rendah tetapi juga untuk mengubah sistem bersiri lain kepada sistem selari.

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LIST OF ABBREVIATIONS

BK	-	Brent-Kung
PPA	-	Parallel Prefix Adder
PISO	-	Parallel input Serial output
PBK	-	Pipeline Brent-kung
WNS	-	Worse Negative Slack
FPGA	-	Field Programmable Gate Array
UTM	-	Universiti Teknologi Malaysia
RTL	-	Register Transfer Level
FA	-	Full Adder
CLA	-	Carry Look Ahead
CSA	-	Carry Select Adder
KSA	-	Koggey Stone Adder
TDR	-	Time Domain Reflectometer
FDR	-	Frequency Domain reflectometer
ANN	-	Artificial Neural Network
GPS	-	Global Positioning System
VCS	-	Verilog Compiler and Simulator

LIST OF SYMBOLS

t_D	-	Death time
f	-	frequency
T_S	-	Slack Time
T_C	-	Circuit Time
T_R	-	Required Time
F_{MAX}	-	Maximum Frequency
λ	-	Wavelength
hc	-	Photon energy
ΔE	-	Energy Transition
Δt_q	-	Quenching Time
Δt_r	-	Recharging Time

CHAPTER 1

INTRODUCTION

1.1 Introduction

Farming involves sequences of steps of preparing the land and the process of cultivating crops. The farmers do these processes manually, which are very difficult to carry out. The processes consist of bush clearing, planting, soil testing, fertilizer application among others. The soil testing is being carried out basically in two broad categories: the traditional method and the other is by using knowledge of Engineering, such as Verilog Hardware Description Language (VHDL), which many agricultural projects are successfully carried out with this knowledge, like irrigation and many more [1]. Furthermore, there is a need for a soil analysis to determine the nutrients and their equivalent quantities present in the soil, which aide expert to recommend the needed amount of fertilizer to complement the deficiency of the existing amount of nutrients in the soil, for efficient and economical production of agricultural produce. Even though most soils have a huge amount of nutrients, when soils are repeatedly used for growing and harvesting crops, nutrients level will subsequently decrease in the soil. Low nutrients level in the soil leads to several crops' disorders and low yield. For a better yield of crop, there is a need to restore the nutrients to the soil by supplementing it. Therefore, the farmers must add macronutrients to the soil in the right proportion. Soil macronutrients are essential nutrients that enhance plant growth in proportion to its level of presence and the required amount. Macronutrients comprise nitrogen (N), phosphorous (P) and potassium (K). N aid leaf and stem development and maintain its green colour, P enhances the root system of the crop for better absorption of water and other beneficial nutrients, and K helps the crops in producing flowers and fruits. The use of fertilizer to meet the demand of the crop by utilizing the advantage of the existing nutrients in the soil is ensured by an appropriate soil test [2]. Additionally, to meet up with the increasing requirement of the rising population over the years, there must be machinery put in place to improve the production of food. There are various sensors used in the field of agriculture for this purpose, some of the sensors are; global positioning system (GPS): for Location sensors, optical sensors: can be measure almost every physical, chemical quantities of interest and electrochemical sensors: pH and soil nutrient levels, Mechanical sensors: use to measure resistive forces in the soil, dielectric sensors, Airflow sensors among others.

To increase crop production, fertilizers containing N, P, and K are crucial. Inappropriate utilization of fertilizers will result in low quality in fruits, vegetables lagging in colour, size, taste and even amount of the fruits. Moreover, the amount of recommended N, P, K is related to the type of crop type and status of plant growth. In addition, the amount of fertilizer to be used is further related to the existing substances of N, P, K macronutrients in the soil. Therefore, Investigators are looking for ways to enhance plant productivity while reducing fertilizer intake. Macronutrients are uniformly varied on a small scale all over a cultivated land; several researchers are involved in finding ways of evolving sensors to map these nutrient contents. The spatial and temporal behavior of N, P, K is checked by integrated crop management systems that were designed for this purpose. To automate agricultural practice, which will improve drop production, monitoring N, P, K values alongside the ph. should be continued [2].

Furthermore, farmers used to send the soil sample to the laboratory for testing, analyzing and get the report back, this type of analysis takes a long time and the sample is analyzed when it is not fresh. To analyze soil nutrients, specific colours are produced from the reaction of the chemical reagents with the soil sample for a particular nutrient. The degree of the presence of nutrient is measured by comparing against a color chart since this is done manually, it is very slow to take days to complete the testing, without quantitative values and lead to errors in the report [3,4] Therefore, there is need to investigate the developed color solution. A spectrophotometer is applied for this purpose, which is faster. However, the system of spectrophotometer became complicated and expensive and needs an operator for proper functioning. The developed of a sensing unit comprises; light emitting diode (LED), photodiode (PD), microcontroller, analog to digital converter (ADC) and general packet radio service (GPRS) modem is reported by Adhikary et. al [3]. The PD received the light beam, which passes through the soil sample that is generated from the light source LED; the received light can be used to compute the presence of the nutrients in the sample. The result from the system shows a little deviation of about 5 % from the Laboratory result, which is according to the researcher is not costly to compare to spectrophotometer and does not requires operator [3]. However, the system is very slow, operates sequentially and requires a network since is a GPRS based which makes it expensive due to data subscription, the color detected is in form of red, green and blue (RGB) which gives less accuracy. To solve this problem, a design was proposed with an architecture of sensing unit based on field programmable gate array (FPGA) system [4], the system is standalone device which has similar procedure with another proposed system, with the exception of GPRS, and instead of computing RGB values directly, the RGB were converted to hue (H) intensity (I) saturation (S) values [3]. The system gives accurate result compared to that RGB, but does not operate in real-time and process data serially. Even though, the macronutrients are the most needed for the purpose of fertilizer application recommendation, zinc (Zn), magnesium (Mg) and calcium (Ca) are also essential nutrients for growth of plants and should be involved in the soil nutrients analysis, so that adequate information on how much specific fertilizer are recommended in a particular section of crop. A solution to this situation was proposed, by developing a program that will give soil pH and six different nutrients level. The nutrients are nitrogen, phosphorous, potassium, zinc, calcium, and magnesium by means of image processing and artificial neural network through MATLAB. After following the same procedure of preparing the soil sample. A camera is used to captures the pictures of the sample for each nutrient, the images are processed through MATLAB, and the model of training is done with an artificial neural network. The program implementation was carried out successfully, and a qualitative result was obtained [5].

Moreover, the artificial neural network requires adequate data training to obtain an accurate result, the training process often takes longer time and operate sequentially, since the system is based on microcontroller, which slows down the operation. The fertilizer recommendation based on the qualitative result of soil nutrients for specific crops will lead to under or over-application of the fertilizer, which is not required. Under the application of fertilizer will lead to plant disorder, and over-application also amounts to a waste of resources, which should be discouraged. The processing speed should be enhanced to fast-track the measurement. The measuring should be improved to handle high-speed parallel data computation.

To solve this problem, this project is proposed to develop a parallel processing system that can handle 16 incoming signals from spectroscopy. The 16 signals are represented by digit 0 to 15. To achieve the implementation of the parallel system, an algorithm and platform that can support parallel processing must be adapted. Parallel prefix (Brent Kung) adder algorithm and FPGA respectively is proposed. 16-bit high speed-processing unit based on FPGA, which is incorporated in spectroscopy. The spectroscopy system comprises a light source that generates light, which is dispersed through monochrome, the optical fiber is used for propagating the light source to a cuvette containing a solution. The solution absorbed some of the light, the absorbance level depends on the concentration of ions in the solution. In addition, some light passed through the solution to the detector where the light energy will be detected and converted to current by photodetector. The weak current is amplified, through the amplify and converted voltage. The analog voltage is converted to a digital voltage by analog to digital converter, which sends the signal to FPGA for processing and counting, the block diagram is presented in Figure 1.1. The FPGA module consists 16-bits buffer that is used to synchronize the unsynchronized incoming signal from the spectroscopy, which is asynchronous. The Brent Kung adder is served as the counter of the signals. A clock divider is used to maintain the appropriate timing for the circuit to operate correctly. The PISO is used to convert the parallel signal to serial. Both buffer and PISO are registers, that is, they are synchronous system, the clock divider is used to ascertain the data integrity at the output of the PISO which is shown in Figure 1.2.

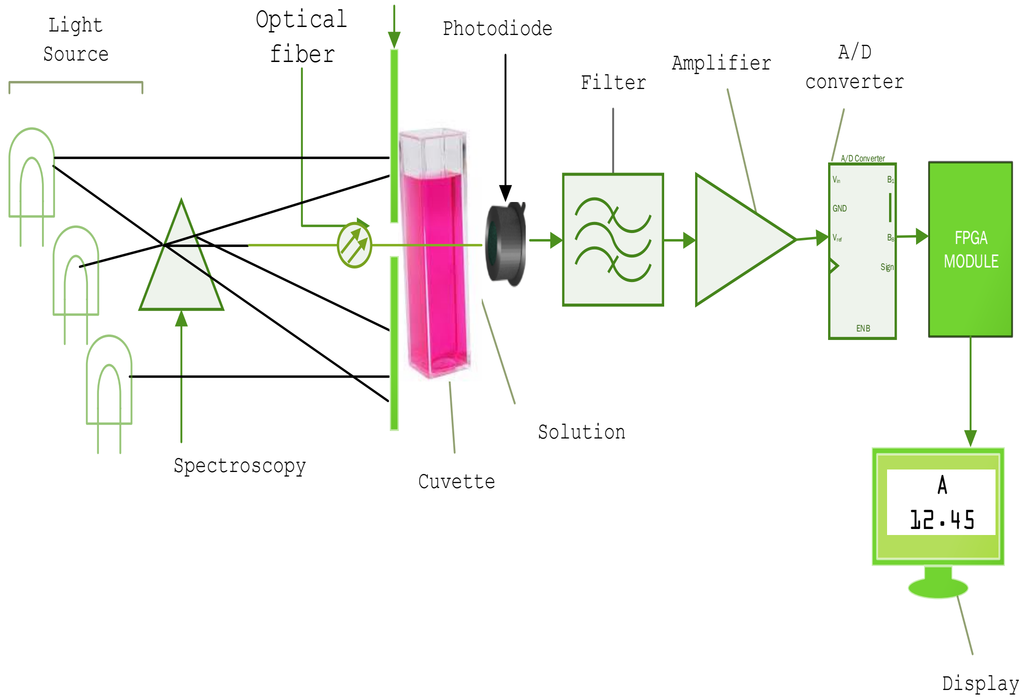

Figure 1.1 Block diagram of the proposed system

1.2 Problem Statement

The overuse or underuse of fertilizer in the farmyard due to inadequate information regarding the presence of nutrients and their corresponding levels should be discouraged.

To analyze soil macronutrients, specific colors are produced from the reaction of the chemical reagents with the soil sample for a particular nutrient. The degree of the presence of nutrients is measured by comparing it against a color chart, which will lead to error and time-consuming. A complicated spectrophotometer is applied for this purpose. However, the system of spectrophotometer needs operator for proper functioning. Another system was developed based on FPGA which can test one sample at a time [5]. Furthermore, a photon counting system was developed based on 16 bits Kogge Stone adder by applying FPGA [6]. The system has high speed with a large area which leads to higher power consumption.

Therefore, there is a needs to utilize the advantages of parallel computing supported by FPGA, to design a new system that will fully support parallel operation and exploit those advantages, by applying Brent Kung adder which has a low area and consequently will lead to lower power consumption.

1.3 Research Objectives

The aim of this project is to develop a high-speed real-time photon counting using FPGA that will operate parallel. Besides this, the analysis of the performance of photon counting will be conducted by adapting Brent Kung adder method. In addition, to analyses the performance of real-time photon counting by using FPGA with various dead time t_D. In other words, the objective can be summarized as follows:

i. To develop a real-time photon-counting simulation in Xilinx Vivado Environment using FPGA

ii. To perform analysis of photon counting by adapting Brent Kung Adder method.

iii. To analyse the performance of real-time soil spectroscopy by using FPGA and Synopsys with various dead time t_D.

1.4 Research Scope

Due to the interaction radiation of electromagnetic, light energy with matter, spectroscopy is very important in identifying compound and its concentration in solution. In absorbance spectroscopy, the system comprises a light source, monochrometer, light detectors, and amplifier as presented in Figure 1.1. LED is used to generate light that illuminates the sample in the cuvette. When the incidence light hits the solution, some of the light is been absorbed by the solution, while the remaining light can be transmitted to the detector (sensor). The photodetector detects the transmitted light and converts it to current (weak). The current is proportional to the intensity of light. The detected weak current signal is amplified and converts to voltage, which then digitizes for the processing in FPGA. The main advantages of spectroscopy are simple to use and accuracy [7].

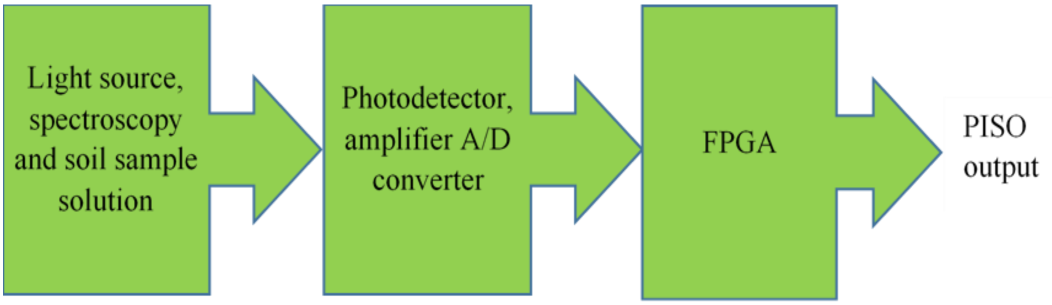

Figure 1.2 Block diagram of the proposed system

The design implementation of the photon counting; consists of 16 bits buffer, 16 bits high speed adder, 16 bits Parallel input Serial output as shown in Figure 1.2. The 16 bits buffer would be used to settle the incoming signal from Spectroscopy to guarantee consistencies of data. 16 bits high-speed adder (Brent Kung adder) served as a counter to the incoming signal from the buffer. The PISO is used to serially arrange the data at the output. The programming language used is Verilog, through Vivado Xilinx 2018 software version 3, for the synthesis and simulation of the design. The analysis of the result was performed and benchmarked with the existing system for the delay, frequency, power consumption and area of the system. The details of the block diagram of the is illustrated in Chapter 3 Figure 3.2.

1.4.1 Advantages of optical sensors over conventional sensors

Optical sensors have significant advantages over the non-optical sensors, based on their properties; some of the advantages are Higher sensitivity, Passiveness of electric, free from interference of electromagnetic, dynamic range very wide, both distributed and points configuration, Capabilities of multiplexing. Furthermore, one can measure almost every physical quantities of interest and very large chemical quantities with optical sensors. The physical quantities such as Temperature, Pressure, flow, liquid level, Position (Displacement), vibration, Magnetic field, Rotation, Radiation, Force, pH values, Acceleration, Acoustic field, Humidity, Velocity, Strain, Electric field, etc. and chemical species [6]. Moreover, some researchers used Arduino/ raspberry pi while other researchers used FPGA.

1.5 Project Report Outline

There are five chapters in this project report. Chapter 1 introduces the objectives of the project and defines the scope of the project.

Chapter 2 then covers some basic sharing towards understanding soil nutrients measurements system operations and their findings. It similarly looks in brief, some of the implementations of different adders towards achieving high speed with comparatively low power consumption implementation.

Chapter 3 then reports on the design implementation from the actual flow of work to some details on the circuits that were implemented for this project.

Chapter 4 discuss the design synthesis and simulating the functionality of the actual implementation of photon-counting circuit and evaluating the result obtained from the simulations.

Chapter 5 focuses on summarizing and drawing a conclusion of the result obtained from the photon counting circuit and briefly explain the future work that can be an improvement from this project implementation. To estimate the parameters

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