BLOOD GLUCOSE MEASUREMENT THROUGH URINE STRIP USING A PHOTOSENSOR

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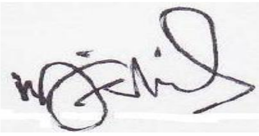

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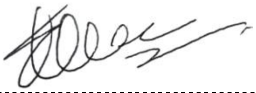

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BLOOD GLUCOSE MEASUREMENT THROUGH URINE STRIP USING A PHOTOSENSOR

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Submitted to the Faculty of Electrical Engineering
in partial fulfillment of the requirements for the award of the
Bachelor of Engineering (Electrical – Medical Electronics)

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APRIL 2010

I declare that this thesis entitled "*Blood Glucose Measurement Through Urine Strip Using A Photosensor*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Dedicated, in thankful appreciation for support, encouragement and understandings
to my beloved father, mother, brother, sister, lecturers and friends.

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ABSTRACT

There are nearly about 1.2 million people in Malaysia who have diabetes. And it is known that diabetes can be diagnosed in human body with normally 2 ways which through blood and urine. The measurement of glucose concentration in the blood is an invasive method whereas the measurement of urine glucose value is a non-invasive method. So, the aim of this project is to develop another method of blood glucose concentration measurement by just using urine of a person only. It is a non-invasive method which only taking the urine sample instead of blood sample. This method is done with finding the relationship between the outputs (in kHz) from the photosensor with the blood glucose values (in mmol/L) obtained from the blood analyzer. A linear relationship has successfully obtained and the blood glucose concentration value will be shown on the personal computer (pc). A system used for blood glucose measurement through urine strip using a photosensor has been successfully developed and the range of measurement is from 0 to 22mmol/L.

ABSTRAK

Di Malaysia, terdapat hampir sebanyak 1.2 juta penduduk yang menghidapi diabetes. Dua kaedah yang biasa digunakan untuk memantau kandungan glukosa di tubuh badan adalah melalui darah dan juga kandungan air kencing. Pemantauan kandungan glukosa melalui darah adalah kaedah secara dalaman manakala melalui kencing adalah kaedah secara luaran. Jadi, satu kaedah yang lain telah ditemui dalam projek ini adalah memantau kandungan glukosa di dalam darah dengan hanya menggunakan sampel kencing seseorang sahaja. Sementara itu,satu hubungan terus antara kandungan glukosa dalam darah dengan hasil keluaran (dalam kHz) melalui photosensor telah ditemui. Dan angka untuk setiap kandungan glukosa dalam darah yang didapati akan dipaparkan dalam sistem komputer. Dengan itu, satu sistem untuk mengukur glukosa darah melalui jalur air kencing dengan menggunakan satu photosensor telah berjaya diciptakan dan julat pengukuran sistem ini adalah bermula dari 0 hingga 22 mmol/L.

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LIST OF ABBREVATION

ADC	-	Analog to Digital Converter
GUI	-	Graphical User Interface
I.C	-	Integrated Circuit
I/O	-	Input/output
PC	-	Personal Computer
VB	-	Visual basic

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Diabetes is a chronic disease in which the body does not produce or properly use insulin, a hormone that is needed to convert starches, and other food into energy needed for daily life. In recent years, the number of diabetic in Malaysia is increasing and we should beware of this silent killer as it leads to many problems like blindness, kidney disease, amputations, heart disease, stroke and many other.

There are many ways can be used to detect our glucose level in our body which using invasive method or non-invasive method. The diagnosis of diabetes is usually done by using invasive method where in this case the sugar level for the pre-meal blood sugar is in a range of 80 to 120 mg/dl whereas the bedtime blood levels are in a range of 100 to 140 mg/dl. The method of this type of detection is by using blood glucose monitoring. By using this method, the person needs to prick a finger in order to get the blood so that testing can be done using the blood.

By the way, the glucose concentration in the body can be checked by using non-invasive method through urine. A detection of glucose concentration is developed by using dipstick urinalysis where a test strip is dipped inside a container contained of a person's urine and then a detection of the glucose can be read on differ in color appear on the test strip.

The amount of concentration of glucose found in urine based on the color changes on urine strip. The glucose concentration in urine for normal physiological range is below 30 mg/dl whereas the abnormal range is above 40 mg/dl. So, it's important for us to check our blood glucose level in our body in an easier and faster way without using any invasive method.

1.2 Problem Statement

It is found out that currently available market products of blood glucose meter cannot be connected to the online system through personal computer. Moreover, most of the measurements for blood glucose concentration tests are done manually by using the invasive method like blood drop and test. So, another approach with non-invasive method is developed to measure blood glucose concentration by just testing on urine using a photosensor.

1.3 Objectives of Project

The main objective of this project is to develop a system that can be used to measure blood glucose concentration using a photosensor. Besides that, the glucose concentration value will be displayed on the screen of personal computer in a quantitative way.

1.4 Scope of Project

In order to achieve the objective of the project, there are several scope had been outlined. The scope of this project includes:

i. Search and buy a suitable photosensor, urine strips, microcontroller, serial PC port and other materials needed in this project.
ii. Design circuit connestions for the photosensor and do testings on it.
iii. Meanwhile, do programming on microcontroller and GUI for the software pat at the same time.
iv. After that, do data collections after the testing and experiments and analysis the results obtained.
v. Improving the results so that more accurate results can be obtained

1.5 Work Breakdown

In order to achieve the objective of this project, there are several tasks that need to be done as shown in Figure 1.1 below. These tasks are divided into three main categories that are study, design and implementation.

The related items that need to study in detail are the principle of the photosensor, urine strips, analog to digital converter, microcontroller architecture, programming for microcontroller and programming for graphical user interface.

Other than that, for this system it is needed to design the system block diagram, hardware circuit, software algorithm and software programming.

Following the design is the implementation of the hardware, software and system integration.

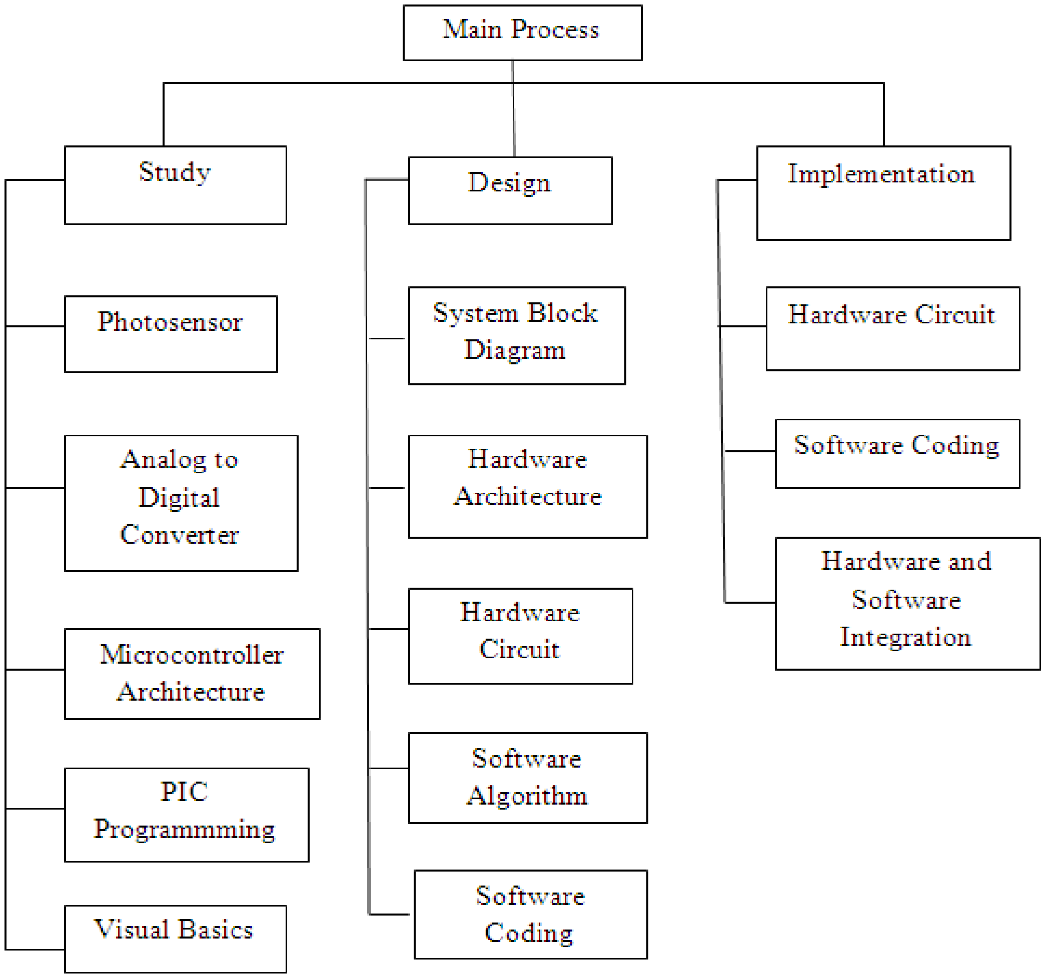

Figure 1.1 Work Breakdowns for the Project

1.6 Work Flow

The summary of work flow for this project is simplified into block diagram as shown in the Figure 1.2 below. The starting point of this project is the literature review and theoretical study. But, these actions are continuous as new information must be gathered from time to time in order to proceed with this project.

After having an overview of the component to include in this project, the suitable components were selected based on the scope and limitation of this project. Hardware implementations begin after the components were available. On the other hand, software implementations begin with algorithm for the analog to digital converter and continue with the graphical user interface. After that, the whole system was integrated for testing and optimization before the real demo and presentation to the panel of the final year project.

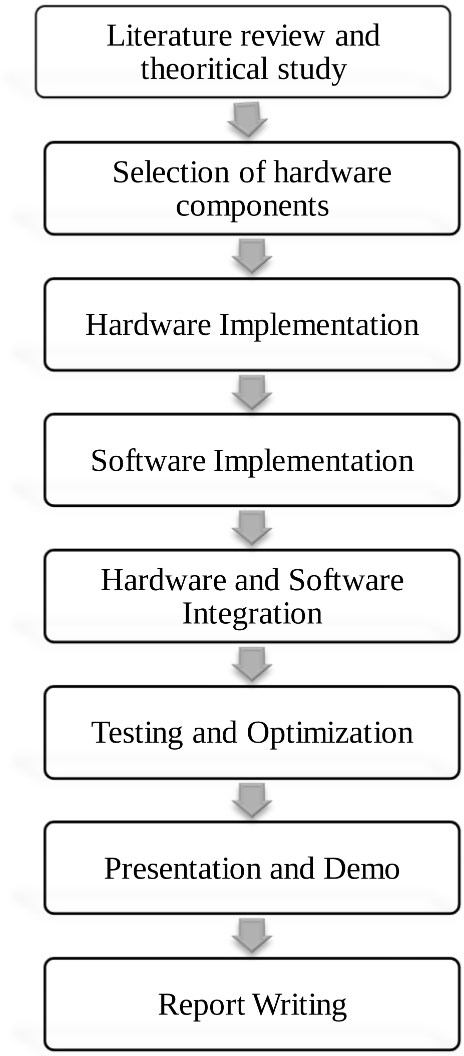

Figure 1.2 Work flow of This Project

Meanwhile, the project schedule or Gantt chart of this project is included in the section 1.7. Gantt chart of Figure 1.3 and Figure 1.4 shows the detail of the works done with the time spending on it for the duration of two semesters.

1.7 Gantt Chart

Implementation and works of the project are summarized as shown in Gantt charts as shown in Table 1.1 and Table 1.2. They show the detail of the works of the project that had been done in the first semester and implement action during second semester.

Table 1.1 : Gantt Chart of the Project Schedule for Semester 1

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.Literature review																Study week	Exam week
2.Study on microcontroller																	
3.Study on Photosensor																	
4.Experimental setup																	
5.Data analysis																	
6.Presentation																	
7.Report writing																	

Table 1.2 : Gantt Chart of the Project Schedule for Semester 2

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.Circuit implementation																Study week	Exam week
2.Software implementation																	
3.Testing and optimization of system																	
4.Presentation																	
5.Demo																	
6.Report writing																	

1.8 Thesis Outline

This thesis is a report of a final year project of title “Blood Glucose Concentration Measurement through Urine Strip Using a Photosensor”. There are five main chapters explained in detail within this thesis.

Chapter 1 explain in detail the information about the project background, problem statement, objectives, scope, work flow, Gantt chart, thesis content and work breakdown. In this chapter, the reader could find out the overview of this project and also the significant of this project.

Next in chapter 2, the related literature to this project is provided in detail. The topic explained in this chapter included medical ultrasound, therapeutic ultrasound, thermal effect of ultrasound and basic of hardware involve.

Chapter 3 is about design and implementation. In this chapter, the design and implementation step is explained in detail.

Chapter 4 contains the information about the results and discussion and the last, Chapter 5 summarizes this project and with recommendations.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the fundamental of photosensor and the principle used to construct the detection of glucose in urine using a photosensor. This chapter also describes the content of urine, types of diabetes, urine strips, color sensor and other relevant fundamentals and components used in the project.

2.1 Formation of Urine

Figure 2.1 below shows the formation of urine on a human being. The production of urine starts from the 2 kidneys by filtration process of blood. After that, it goes to urinary bladder following the 2 ureters. When the volume exceeds the maximum, the urine will be excreted out through urethra. In urine, there are 96% of water and 4% of solutes chemical that are dissolved in the water. The solutes are composed of waste like urea, uric acid and creatinine, sodium, potassium, calcium, magnesium, phosphates, sulphates, nitrites, chlorides and hydrogen carbonate, organic acids, ammonia as ammonium salts, drugs and hormone metabolites. Some of these solutes are produced as the results of normal biochemical activity within the cells of human body whereas the other solutes may be due to chemicals that come from outside of the body like pharmaceutical drugs. The solutes inside the urine as ions or organic molecules can be classified.

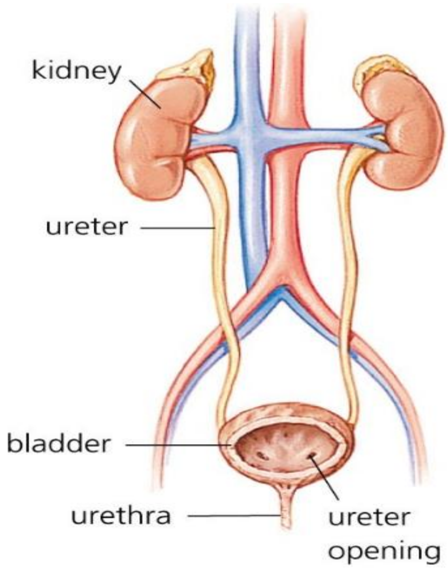

Figure 2.1 Formation of Urine

The urine produced by a normal adult is between 1 and 1.5 litres per day but infant has much greater volume in proportion to his/her small body size. The volume and composition of urine produced depending on age, fluid intake, diet, climate, activity and health of a person [1].

2.2 Types of Diabetes

Diabetes is a chronic and life-long disease due to high levels of glucose in the blood that caused by too little insulin (a hormone produced by pancreas to control the blood glucose), resistance to insulin or both. In simple words, when normal people eat, the pancreas will automatically produce the right amount of insulin to move glucose from blood into the cells whereas in people with diabetes, the pancreas will either produce little or no insulin, or the cells do not respond appropriately to the insulin produced. There are 3 major types of diabetes nowadays:

i. Type 1 diabetes: It is also called 'juvenile diabetes' or 'insulin-dependent diabetes'. The body can make little or no insulin and thus insulin injections are needed. This type of diabetes occurs before age 30, mostly found in children, but may occur at any age [2].

ii. Type 2 diabetes: Most common form of diabetes and most often associated with older age, obesity, family history, previous history of gestational diabetes, certain ethnicities and physical inactivity. The body does not respond well to the insulin and the pancreas does not make enough insulin to keep the blood glucose level in normal range [3].
iii. Gestational diabetes: It is found for the first time when a woman is pregnant who does not have diabetes before that and due to changing hormones and weight gain during pregnancy causing high blood glucose level. These changes make the body hard to keep up with the need of insulin. It is temporary only as it will mostly go away after the baby is born by managing diet and exercise. It is also called glucose intolerance in pregnancy [4].

2.3 Diagnostic Devices Used To Detect Glucose Level

2.3.1 Blood Glucose Meter

A glucose meter (or glucometer) is a portable medical device used to determine the approximate concentration of glucose in the blood wherever and whenever we are. We can test for glucose by placing a small sample of blood on a disposable test strip and then place the strip in the meter. The test strips are coated with chemicals like glucose oxidase, dehydrogenase, or hexokinase that will combine with glucose in blood. The meter will read, calculate and display the blood glucose level in mg/dl or mmol/dl.

Different meter will detect the glucose level in different ways. Some of them measure the amount of electricity that can pass through the sample whereas others measure how much light reflects from the sample.

Most of the meter are able to measure and display the glucose level from a range of as low as 0 to as high as 600mg/dl. We can convert mmol/dl of glucose to mg/dl, multiply by 18 or convert mg/dl of glucose to mmol/dl, divide by 18 or multiply by 0.055. Calibrations needed to be done for the glucose meter if there the readings are extremely low or high in value.

Figure 2.2 Blood Glucose Meter

Figure 2.3 Flow of Blood Glucose Testing

These are some examples of blood glucose meters as shown in Figure 2.2. There are many types of blood glucose meters available in the markets with different brand and specifications that will suit user's needs. Figure 2.3 shows the flow of testing the glucose level in the blood using the test strips. Patients can monitor their blood glucose level at home everyday so that they can be aware and know better of their blood glucose levels.

2.3.2 Urysis 1100

Another apparatus that is commonly used to detect glucose level in our body is by using Urisys 1100 as shown in Figure 2.4 [5]. This is a different method compared to blood glucose meter as the sample used to detect glucose level in Urisys 1100 is urine but not blood. It is a reflectance photometer designed to read and evaluate the urine test strips Combur10Test UX, Combur7Test and Combur5Test from Roche Diagnostics. It reads the strips under standardized conditions, saves the results to memory and outputs them via its own inbuilt printer and/or serial interface. This instrument is designed for In Vitro Diagnostic (IVD) used by qualified physicians and laboratory staffs. The test strip is placed on a sliding tray, and a stepping motor moves it under the reading head, which remains stationary. The analyzer reads the reference pad, followed by each of the test pad on the strip.

Figure 2.4 Urisys 1100

The reading head contains LEDs that emit light at various wavelengths. Reading is done electro-optically, as shown in Figure 2.5 as follows:

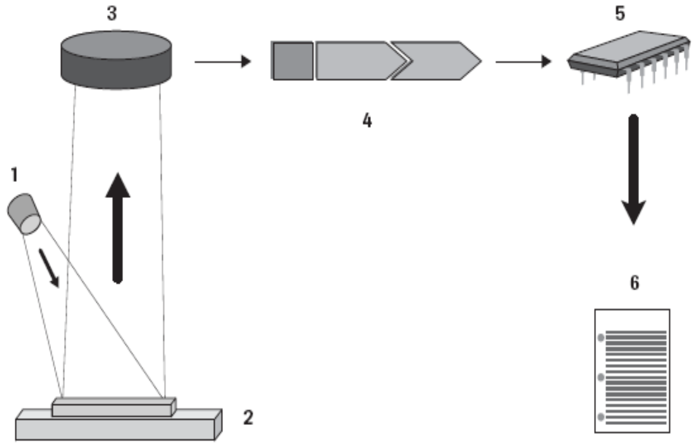

Figure 2.5 Flow System of Urisys 1100

The LED (1) emits light of a defined wavelength on to the surface of the test pad (2) at an optimum angle. The light hitting the test zone is reflected more or less intensely depending on the color produced on the test pad, and is picked up by the detector, a phototransistor (3) positioned directly above the test zone. The phototransistor sends an analogue electrical signal to an A/D converter (4), which changes it to digital form. The microprocessor (5) then converts this digital reading to a relative reflectance value by referring it to a calibration standard. Finally, the system compares the reflectance value with the defined range limits (reflectance values that are programmed into the analyzer for each parameter) and outputs a semi-quantitative result (6). Each test pad is read photo metrically after a lead (incubation) time of about 55–65 seconds. In strongly alkaline urine samples, Urisys 1100 automatically corrects the result of the Specific Gravity test.

2.4 Urine Strips

There is a wide range of urine reagent strip tests available in the markets with many types of parameters can be tested. Range of parameters that is available in the markets nowadays can be from 1 to 11 parameters. These parameters are glucose, ascorbic acid, ketones, protein, pH-value, blood, nitrite, leukocytes, specific gravity, bilirubin and urobilinogen.

The Roche and Bayer reagent strips that can be used to test glucose in urine are Clinistix, Diabur-Test 5000, Diastix, Uristix, Keto-Diabur-Test, Combur 3 Test E, Keto-Diastix, Combur 3 Test, Combur 4 Test (or with N), Combur 5 Test (or N), Lobtix (or with N), Combur 6 Test, Lobstix SG, Combur 7 Test, Multistix SG, Combur 9 Test, N-Mustistix SG, Combur 10 Test, Multistix 8 SG and Multistix 10 SG [6].

Figure 2.6 Examples of Urine Strips

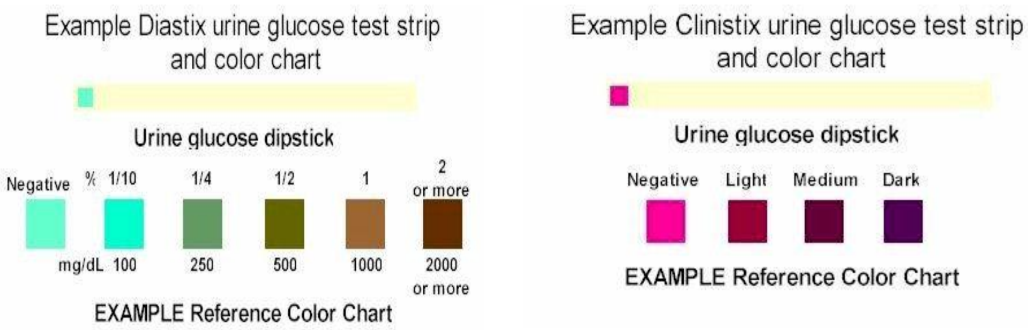

Figure 2.7 Examples of Reference Color Chart

These are some types of urine strips with different parameters found in the markets as shown in Figure 2.6 and Figure 2.7 shows some examples of reference color chart that can be used for visual test. The chemical reactions involved in the urine strip for glucose test is shown in Figure 2.8

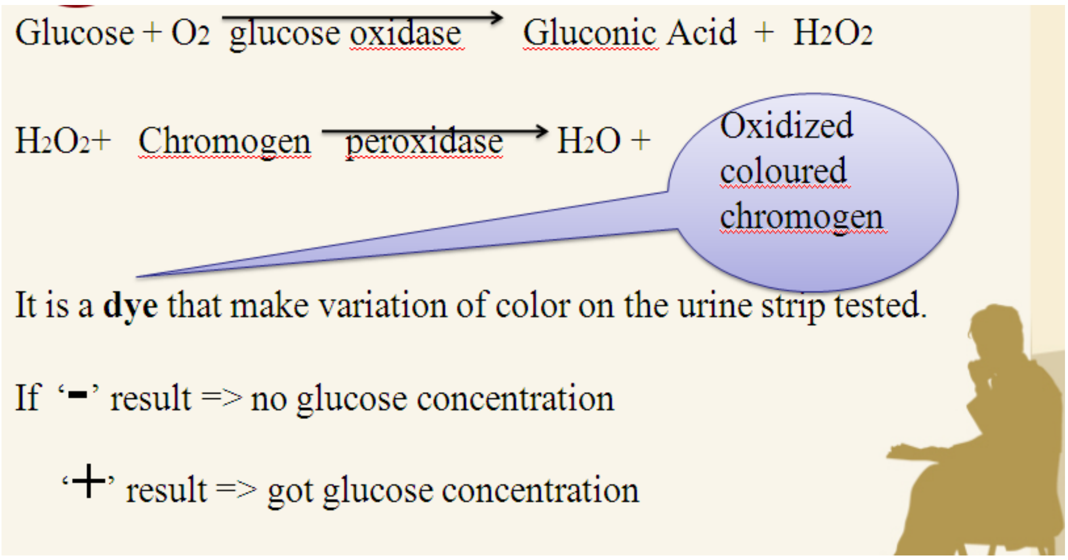

Figure 2.8 Chemical Reactions for Glucose Test inside a Urine Strip

2.5 Unit Used for Glucose Concentration In Human Body

There are two main methods of describing concentrations: by weight, and by molecular count. Weights are in grams, molecular counts in moles (a mole is 6.023×10^{23} molecules). In both cases, the unit is usually modified by milli- or micro- or other prefix, and is always "per" some volume, often a liter.

Mmol/l is millimoles/liter, and is the world standard unit for measuring glucose in blood. Specifically, it is the designated SI (System International) unit. "World standard", of course, means that mmol/L is used everywhere in the world except in the US.

Mg/dl (milligrams/deciliter) is the traditional unit for measuring bG (blood glucose). All scientific journals are moving quickly toward using mmol/L exclusively. mg/dl won't disappear soon, and some journals now use mmol/L as the primary unit but quote mg/dl in parentheses, reflecting the large base of health care providers and researchers (not to mention patients) who are already familiar with mg/dl.

To convert mmol/l of glucose to mg/dl, multiply by 18 whereas to convert mg/dl of glucose to mmol/l, divide by 18 or multiply by 0.055. [8]

2.6 Principle of Reflective Colorsensor

Color produced is due to the result of interaction between a light source, an object and an observer. In the case of reflected light, light falling on an object will be reflected or absorbed depending on surface characteristics such as reflectance and transmittance. For example, red paper will absorb most of the greenish and bluish part of the spectrum while reflecting the reddish part of the spectrum, making it appear reddish to the observer. For self-illuminated objects, the light will reach the human eye and will be processed by the eye's receptors, and interpreted by the nervous system and brain. There are three types of color sensors: a) light to photocurrent, b) light to analog voltage and c) light to digital. Reflective color sensing is typically realized through photodiodes with multiple illuminant or photodiodes coated with color filters with single illuminant. Three important elements in reflective sensing:

i. Detector- It’s a device that captures light reflected from an object.
ii. Target- It’s an object whose color is measured, like colored paper or paint. It is typically non-emissive, reflects and absorbs different amounts of light at different wavelengths.
iii. Illuminant- It’s a light source whose spectrum covers the visible wavelengths, like sunlight.

Figure 2.9 shows a light to analog voltage Colorsensor with an array of photodiodes behind color filters and an integrated current to voltage conversion circuit. Besides that, Figure 2.10 shows the color of reflected light depends on the colors that a surface reflects and absorbs.

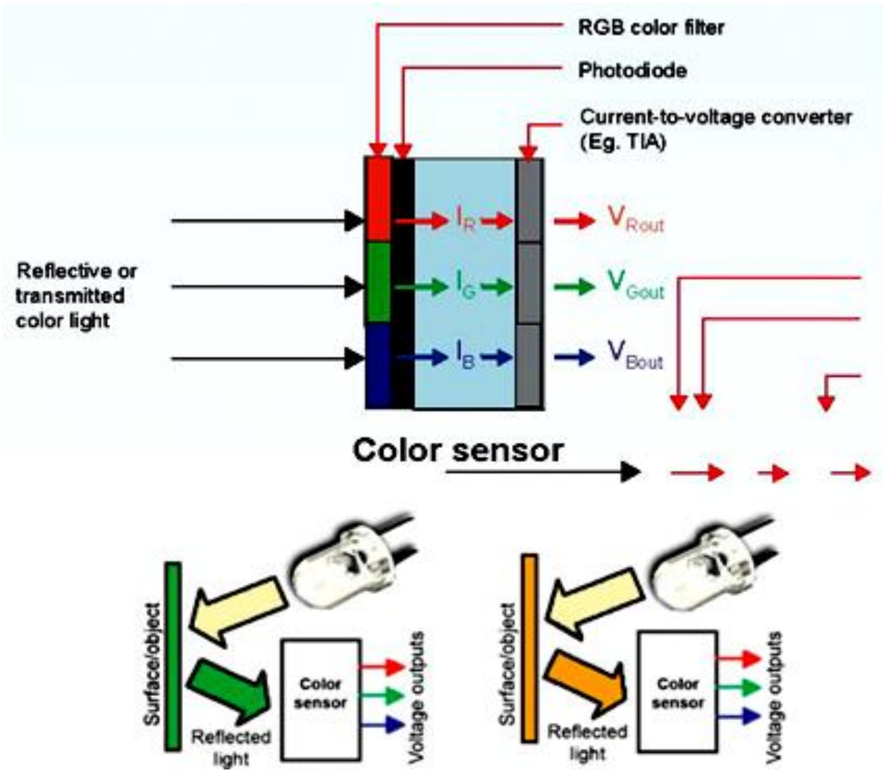

Figure 2.9 A Light to Analog Voltage Colorsensor With An Array of Photodiodes Behind Color Filters And An Integrated Current to Voltage Conversion Circuit

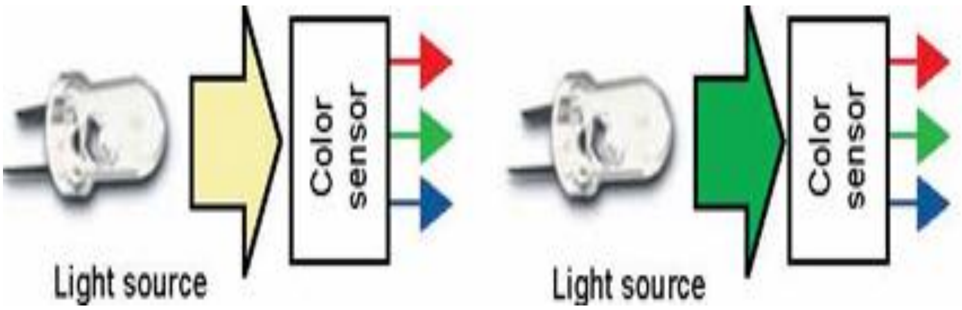

Figure 2.10 Color of Reflected Light Depends On the Colors that A Surface Reflects And Absorbs

The human visual system can detect the electromagnetic spectrum from about 400nm (violet) to about 700nm (red). In addition, human visual system can adapt to widely varying illumination levels and amounts of color saturation (the proportion of pure color to white).

There are three sets of cones with peak sensitivities at wavelengths that can be identified as red (580nm), green (540nm) and blue (450nm) and light at any wavelength in the visual spectrum will excite one or more of these three types of cone cells to varying degrees, with our perception of the color being that information as processed by our optic nerve and brain.

Generally, colorimetric and photometric are two types of measuring instruments. By using the colorimetric method, the device measures light from an object using a sensor with three filters. Normally, the sensor profile is optimized so that it will closely resemble the human eye response. The photometric method uses a multiplicity of sensors to measure color over a large number of narrow wavelength ranges. The instrument's microcomputer then calculates the tristimulus values by integrating the resulting data. Figure 2.11 shows the red, green and blue ouputs of the sensor are determined by the color of light falling on the sensor.

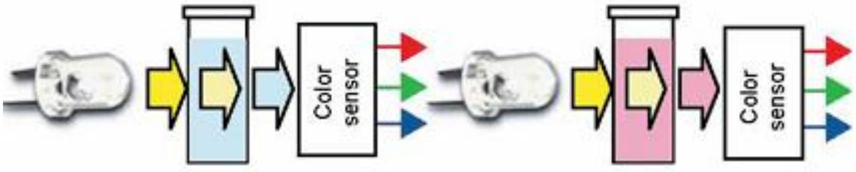

Figure 2.11 The Red, Green and Blue Outputs of Color Sensor

The spectral response of the individual Red, Green and Blue channel should be overlapping to ensure all wavelength information is captured. Figures 2.12 and 2.13 below show the overlapping and non-overlapping spectral responses respectively.

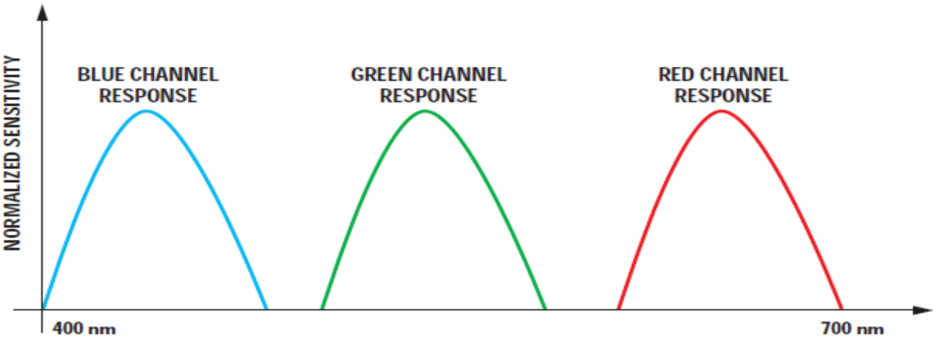

Figure 2.12 Non-overlapping Spectral Response

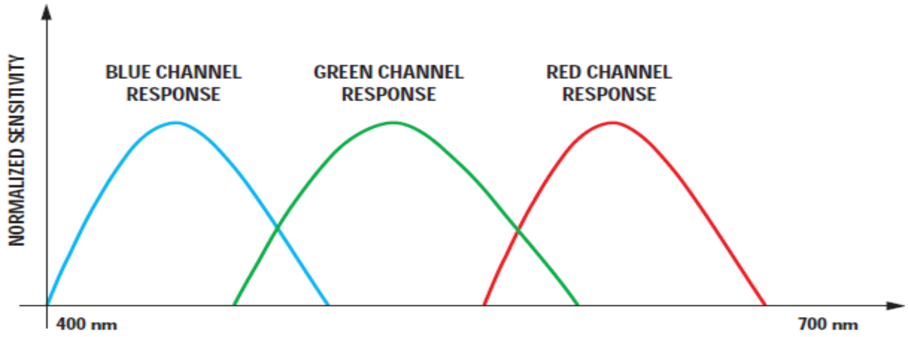

Figure 2.13 Overlapping Spectral Rsponse

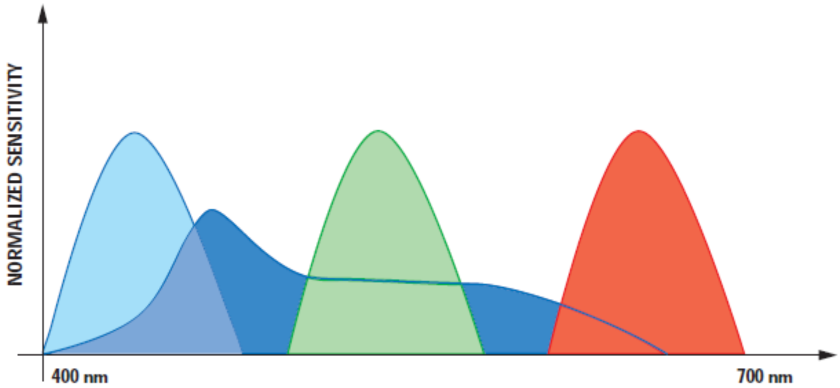

Figure 2.14 Sensor Spectral Overlaps With Reflected Light Not Captured By Sensor

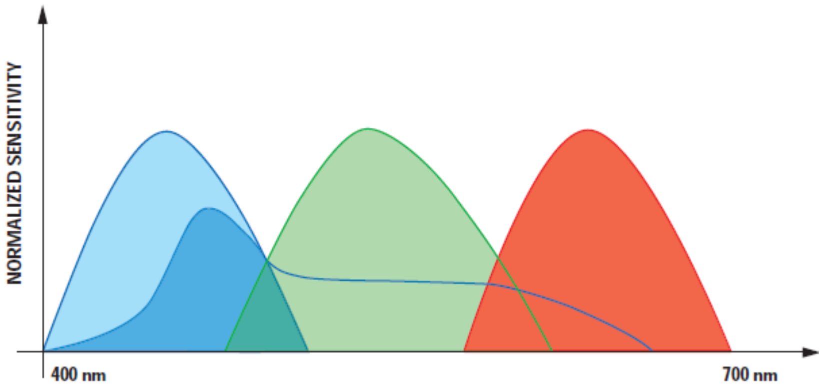

Figure 2.15 Sensor Spectral Overlaps With Reflected Light Captured By Sensor

In a mathematical way, sensor output is directly proportional to the overlapping area of the reflected signal and sensor spectral profile. Figure 2.14 shows there are two non-overlapping areas which mean the information in that region will not be captured by the sensor. Figure 2.15 shows the information of the reflected signal is properly captured by the sensor with an overlapping spectral response.

So, light falling on each of the photodiodes is converted into a photocurrent, the magnitude of which is dependent on both the brightness and, due to the color filter, wavelength of the incident light. In addition, without a color filter, a typical silicon photodiode responds to wavelengths ranging from the ultraviolet region through the visible, with a peak response region between 800nm and 950nm in the near-IR part of the spectrum. The red, green and blue transmissive color filters will reshape and optimize the photodiode's spectral response.

In reflective sensing, the color sensor detects light reflected from a surface or object, with both the light source and the color sensor placed close to the target surface. Light from the light source bounces off the surface, and is measured by the color sensor. The color of the light reflected off the surface is a function of the color of the surface. For instant, white light incident onto a red surface is reflected as red. The reflected red light collides on the color sensor producing red, green and blue output voltages. By interpreting the three voltages, the color can be determined. Since the three output voltages increase linearly with the intensity of the reflected light, the color sensor also measures the reflectivity of the surface or object. [9]

2.7 Microcontroller

A microcontroller is a small computer on a single integrated circuit consisting of a relatively simple CPU combined with support functions such as a crystal oscillator, timers, watchdog, serial and analog I/O. Program memory in the form of NOR flash or OTP ROM is often also included on chip, as well as a typically small read/write memory. It is design for small applications compare to microprocessors and are used in automatically controlled products and devices, such as automobile engine, control systems, remote control, and many other applications.

Since embedded processors are usually used to control devices, they sometimes need to accept input from the device they are controlling. This is the purpose of the analog to digital converter. Since processors are built to interpret and process digital data, such as 1s and 0s, they won't be able to do anything with the analog signals that may be being sent to it by a device.

So the analog to digital converter is used to convert the incoming data into a form that the processor can recognize. There is also a digital to analog converter that allows the processor to send data to the device it is controlling.

2.8 Serial Port Interface-UC00A Method (USB to UART Convertor)

Serial communication is the most popular interface between device and this applies to microcontroller and computer. UART (Universal Asynchronous Receiver Transmitter) is one of those serial interfaces. Classically, most serial interface from microcontroller to computer is done through serial port (DB9). However, since computer serial port used RS232 protocol and microcontroller used TTL UART, a level shifter is needed between these interfaces. Recently, serial port of computer have been phase out, it have been replaced with USB. Of course most developers choose USB to serial converter to obtain virtual serial port. The level shifter is still necessary for UART interface. A USB to UART converter is developed which offers USB plug and play, direct interface with microcontroller and is provided with low current 5V supply from USB port. Figure 2.16 shows the traditional method of serial port interface for PC whereas Figure 2.17 shows serial port for PC by using a USB. Now, an easier, cost-saving and much convenient method of serial port is developed by using UC00A method. [10]

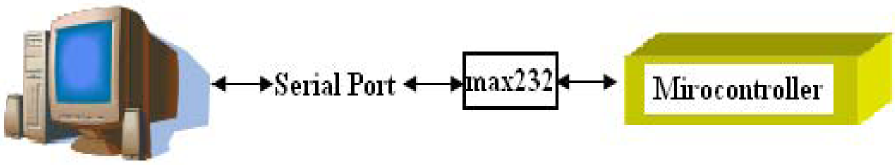

Figure 2.16 Traditional Method of Serial Port for PC

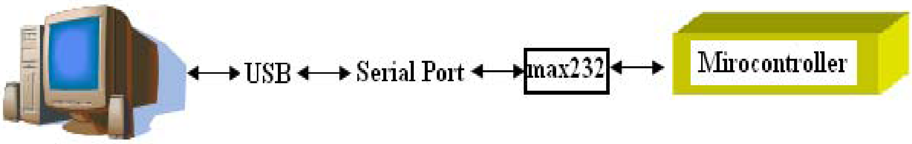

Figure 2.17 Serial Port for PC Using USB

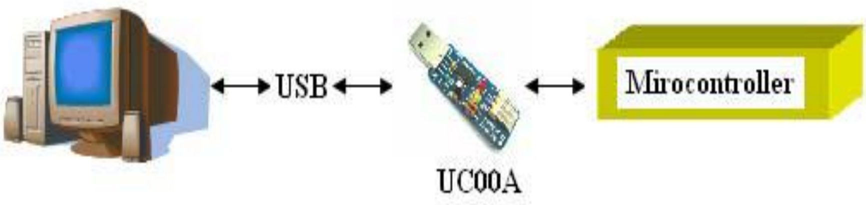

Figure 2.18 Serial Port for PC Using UC00A Method

The features and specifications of UCOOA will be shown in Appendix A there.

2.9 SK40C ENHANCED 40 PINS PIC START-UP KIT

SK40C as shown in Figure 2.19 is another enhanced version of 40 pins PIC microcontroller start up kit. It is designed to offer an easy-to-start board for PIC user. However, all interfaces and program should be developed by user. This board comes with basic element for user to begin project development. It offer plug and use features. More features and specifications can refer to Appendix B.

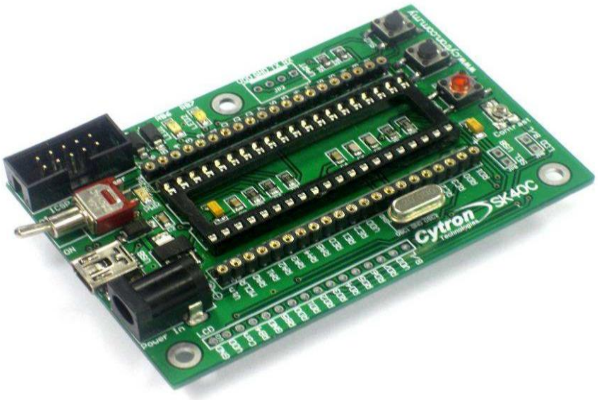

Figure 2.19 SK40C Enhanced 40 Pins PIC Start-up Kit

2.10 Toggle Switch Single Pole Double Throw (SPDT)

Since there are four possible variable inputs for different filter need to be selected which are red filter, green filter, blue filter and clear filter, so it's necessary to use switches for selecting wanted inputs. I have chosen toggle switches SPDT as my input selector in my project. The number of poles indicates how many completely independent circuits are controlled by the switch. The number of throws indicates the number of positions that will result in an electrical connection.

Figure 2.20 shows the basic structure of toggle switch SPDT. The green color line in Figure 2.20 shows the path that the current will follow and the power source can be connected to any of the terminals. If the power source is connected to the centre terminal, it can go to either of the other 2 terminals but if the power source is connected to either of the outside terminals, it can only be switched to the centre terminal. This means that one terminal will always be dead (no connection to the power source). Figure 2.21 shows the symbol of toggle switch and its example. [11]

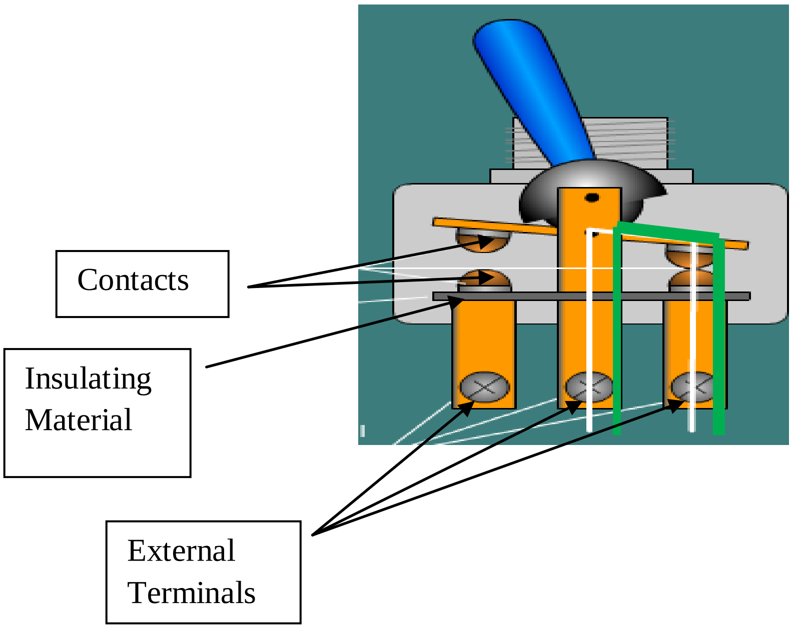

Figure 2.20 Basic Toggle Switch Structure

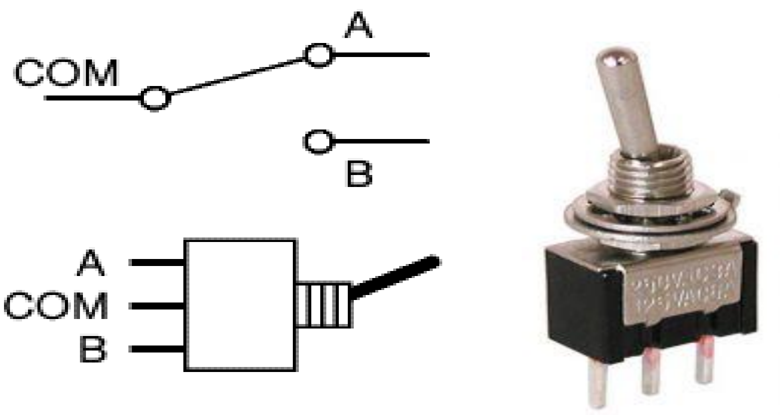

Figure 2.21 Symbols and Example of Toggle Switch SPDT

2.11 Visual Basic.NET (VB.NET)

VB.NET is an extension of Visual Basic (VB) programming language with many new features in it and the changes from VB to VB.NET are huge, ranging from the change in syntax of the language to the types of project we create now and the way we design applications.

VB.NET was designed to take advantages of the .NET Framework base classes and runtime environment. It comes with power packed features that simplify application development. The industry is focusing on critical distributed computing with web services capabilities. At this moment VB.NET is definitely a powerful tool to provide all these solutions in integrated environment of .NET technology. Below are the major problems with VB 6.0, which has been creating troubles for VB developers for a long time. [12]

Problems with VB 6.0:

i. Poor error handling capabilities
ii. No capabilities for multithreading.
iii. Lack of implementation inheritance and other object oriented features.
iv. No effective user interface for Internet based applications.
v. Poor integration with other languages such as C++.

Improvement found in VB.NET:

i. Full support for object oriented programming.
ii. Better database programming approach with ADO.NET.
iii. Access to .NET Framework.
iv. Powerful unified Integrated Development Environment (IDE).
v. Inherent support for XML & Web Services.
vi. Better windows applications with Windows Forms.
vii. New Console capabilities of VB.NET.
viii. New Web capabilities with Web Forms.
ix. Structured error handling capabilities
x. Immense power of tools & controls (including Server Controls).
xi. Interoperatibility with other .NET compiled languages.

CHAPTER 3

DESIGN AND IMPLEMENTATION

This chapter describes the design and implementation for the blood glucose measurement through urine strip using a photosensor.

3.1 Introduction

Figure 3.1 shows the block diagram of main system design. Basically, there were hardware and software need to be implemented in this project.

Hardware part consists of photosensor circuit connection including PCB design, photosensor box design and serial port interface connection like USB converter that connected from PIC to personal computer.

Meanwhile, the software part includes microcontroller as analog to digital converter that read the analog urine glucose value measured by the photosensor and converts it to digital number has been developed in PIC using Assembly Language programming. Besides that, graphical unit interface (GUI) using Visual Basic was programmed to display the calculated blood glucose value on the personal computer.

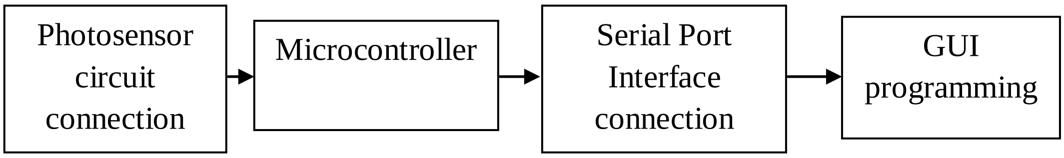

Figure 3.1 Block Diagram of the Design System

3.2 Hardware Implementation

3.2.1 Photosensor used: Reflective Color Sensor Assembly OPT780Z

Figure 3.2 shows the Reflective Color Sensor Assembly OPT780Z that used in this project. The main reason that I chose this sensor for my project was because of its colormetry and chemical analyzers applications that suit my needs in my project. It had selectable color output frequency with 2 digital inputs.

Figure 3.2 Reflective Color Sensor Assembly OPT780Z

The output of this sensor is a square wave (50% duty cycle) with a frequency directly proportional to reflected light intensity (irradiance). In addition, the output of the sensor can be connected to TTL or CMOS logic input as well as microcontroller. This sensor can be used to detect the glucose concentration in the urine strip because it can detect the color change on the urine strip and a frequency output will be produced with a certain value measured in kHz. In addition, more details of this sensor can refer to the Appendix C.

3.2.2 Printed Circuit Board (PCB) Design for Photosensor

Since the photosensor is the main part of this system as it is used to detect the color change on the urine strip, so i need to choose appropriate materials and electronic components to connect this photosensor. At first, I connected the outputs of photosensor into a designed and made printed circuit board (PCB).

Figure 3.3 shows the PCB design using software and the connections for photosensor output before the photosensor can be implemented by connecting it into the protoboard. There were 8 outputs from the photosensor that need to be connected to different another outputs.

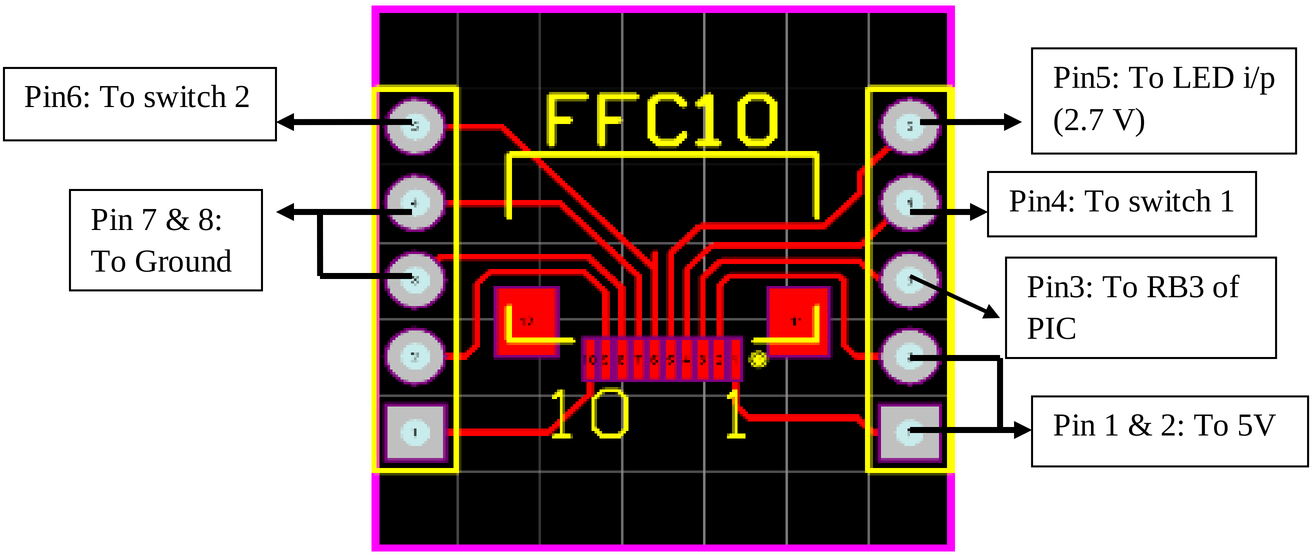

Figure 3.3 PCB Design And Connection for Photosensor Output

The listings of components used to connect the whole photosensor circuit were shown in Table 3.1. The photosensor used is OPB780Z.

Table 3.1 : Components that build up photosensor circuit

Number	Components	Description
1.	2 Toggle Switches SPDT	As digital inputs for the photosensor
2.	1 Toggle Switch SPDT	Used for battery switch
3.	Battery	9V
4.	Zener Diode	0.5W 2.7V
5.	Resistor	¼ Watt 560Ω
6.	Voltage Regulator	KA7805
7.	Microcontroller	PIC18F452
8.	USB to UART Convertor	UC00A
9.	SK40C ENHANCED 40 PINS	PIC START-UP KIT

3.2.3 Switches

Three switches were used in this project: 2 for inputs of photosensor and 1 for portable power supply. There were four variable logical inputs in the photosensor which red, green, blue and clear filters that shown in Table 3.2. Each filter or input of the photosensor controlled by two separately toggle twitches SPDT in Low (L) or High (H) conditions. For instant, a clear filter or input selected when switch 1 is set High (H) and switch 2 is set Low (L). High (H) means 5V and Low (L) means Ground (GRD).

Table 3.2 : Table of Variable Inputs of Photosensor

Filter type	Switch 1	Switch 2
Red	L	L
Green	H	H
Blue	L	H
Clear	H	L

3.2.3.1 For 4 Variable Logical Inputs of Photosensor

Figure 3.4 shows the switch 1 and switch 2 connections for input selecting from the four variable logical inputs of the photosensor.

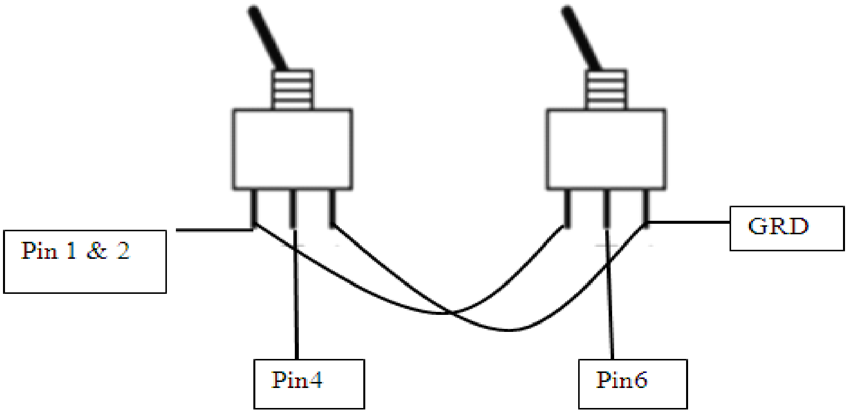

Figure 3.4 Switch 1(Left) and Switch 2(Right) Connections for Photosensor Inputs

3.2.3.2 For Portable Power Supply

The portable power supply (9V battery) was controlled by switching on and off through a toggle switch SPDT and the switch connections shown in Figure 3.5.

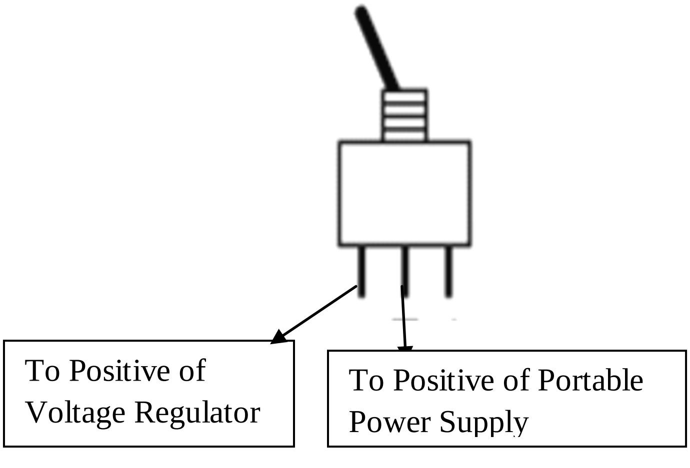

Figure 3.5 Switch Connections for Portable Power Supply

3.2.4 Troubleshooting by Making a Portable Power Supply

A portable power supply was designed and implemented due to the conveniences on doing samples testing at Pusat Kesihatan UTM. The schematic diagram of the portable power supply shown on Figure 3.6 and it was simulated using Multisim software before it was implemented in real circuit. The main reasons for implementing this circuit are regulating the 9V battery to 5V (will be connected to pin 1 & 2) and 2.7V (will be connected to pin 5) respectively.

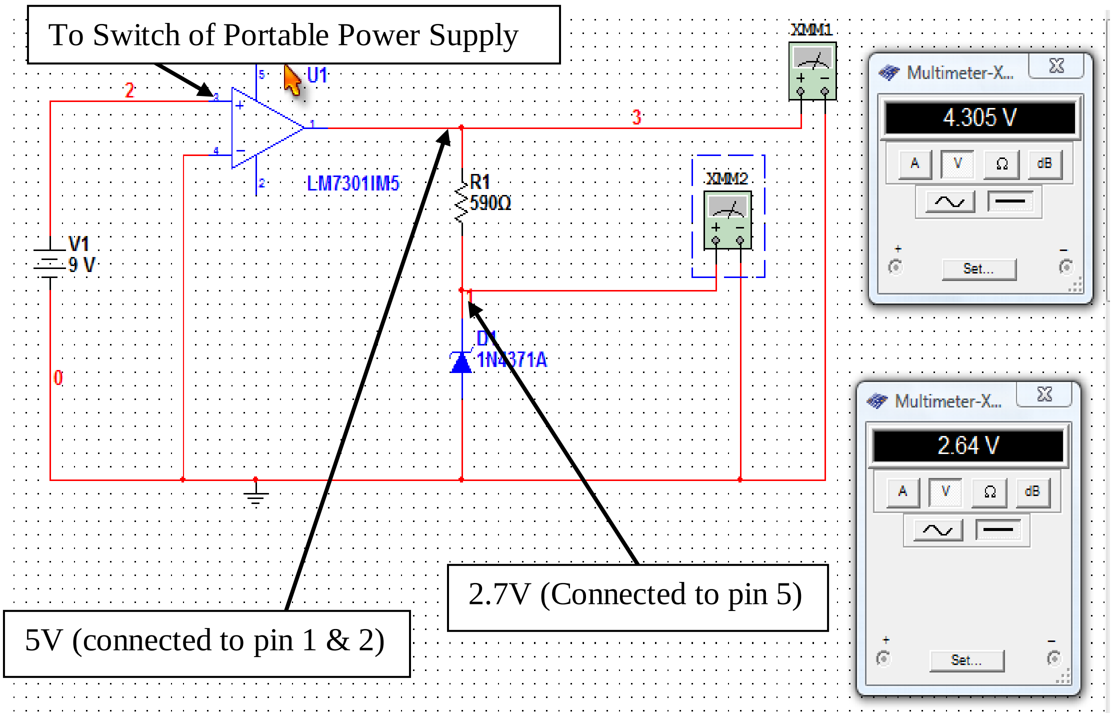

Figure 3.6 Schematic Diagram for Portable Power Supply

3.2.5 Embedded ADC in PIC16F877A Microcontroller

In this project, embedded ADC in PIC16F877A was used. Figure 3.7 shows the image and the pin diagram of the microcontroller used. RB3 pin was connected to pin 3, VDD pin was connected to pin 1 & 2 and VSS pin was connected to pin 7 & 8 of the photosensor pins respectively. Output from the ADC was connected to personal computer through serial port interface.

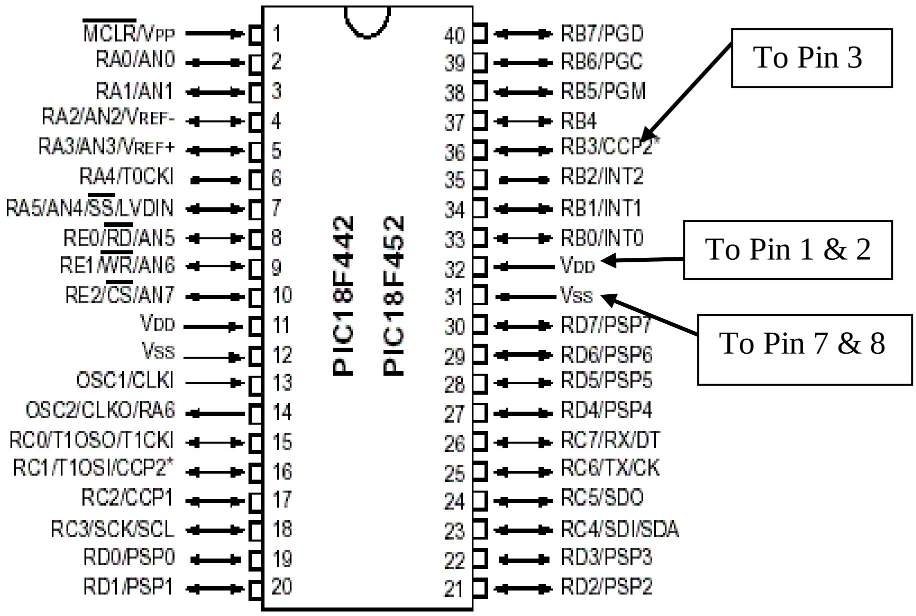

Figure 3.7 Image and Pin Connections of PIC18F452

3.2.6 Photosensor Box

A box with length of 24cm and width of 14cm was built to provide a dark environment for the photosensor so that accurate testing of samples can be assured. Figure 3.8 shows the external look and internal look of photosensor box.

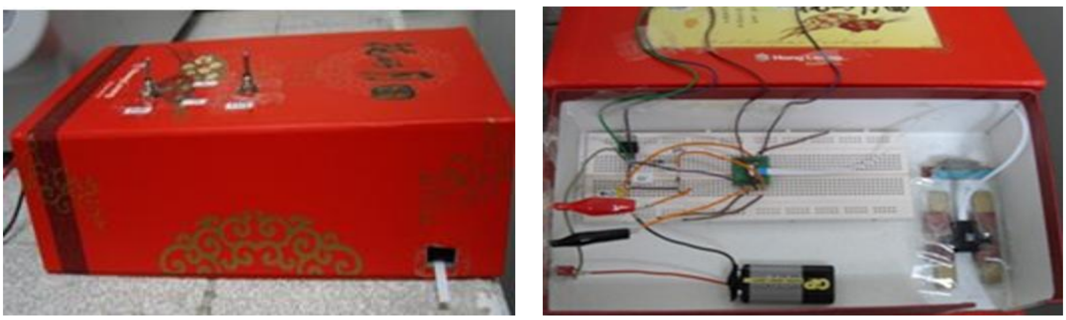

Figure 3.8 External (Left) and Internal (Right) Look of Photosensor Box

Besides that, the photosensor was constructed as shown in Figure 3.9 so that it can stand still alone. A distance of approximately 0.6cm was set and measured from below of the photosensor to the ground of the photosensor box as shown in Figure 3.10.

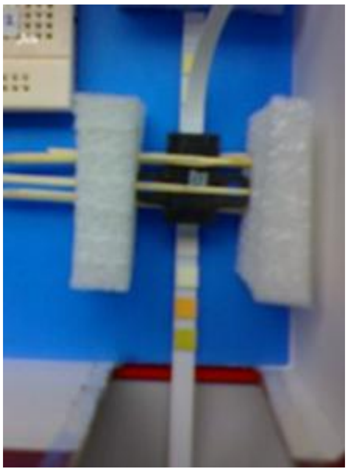

Figure 3.9 Photosensor Construction

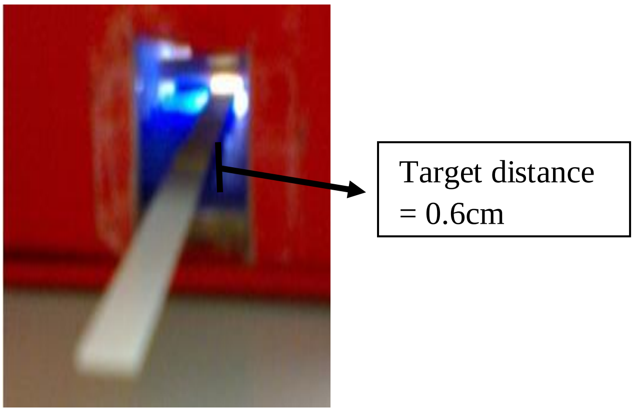

Figure 3.10 Target Distance

3.3 Software Implementation

For software implementation, PIC Programmer was used to write and compile the program of the microcontroller. Meanwhile, PIC kit (SK40C ENHANCED 40 PINS PIC START-UP KIT) was used to load the hex file from the PIC Programmer to the microcontroller and then transferred the data from PIC to PC through a UC00A connection. Other than that, VB.NET was used for programming the user interface and displayed the data which received from PIC through UC00A into the screen of PC.

3.3.1 Analog to Digital (A/D) Converter (ADC) of PIC18F452

Figure 3.11 shows the flow chart of how to setup ADC and read the value of ADC from the PIC 18F452 Microcontroller. The written code that compiled by PIC Programmer were loaded into PIC18F452 in hex file format. Then, the internal build in ADC digitalized the signal coming from output of the photosensor. Explanations of source codes can be referred to Appendix D.

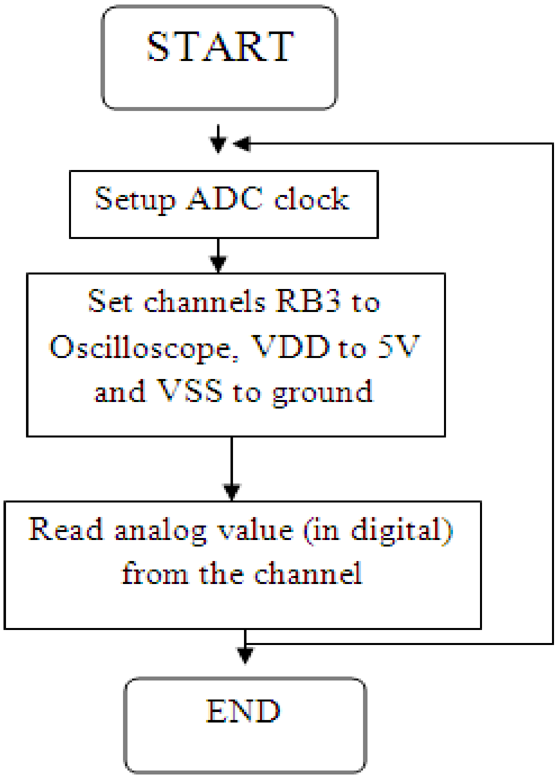

Figure 3.11 Flow Chart of A/D Converter

3.3.2 Graphical Unit for User Interface (GUI)

Graphical user interface for this project were developed in VB.NET. The purpose of this graphical user interface was to display the blood glucose concentration value (mmol/L). The flow of this GUI was shown in Figure 3.12. All the detail on VB.NET code been applied were elaborated in Appendix E.

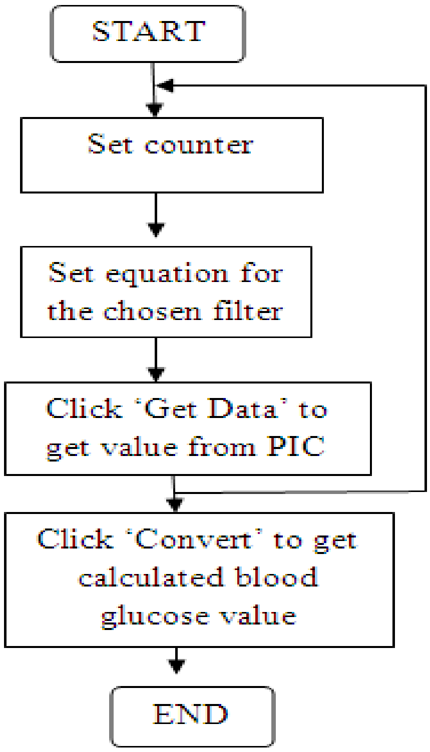

Figure 3.12 Flow Chart of GUI Display

Figure 3.13 illustrates the window where it contains of buttons, text boxes and message box. At Form 1, the function of 'Get Data' button was to receive data from the output of photosensor to PIC and then to PC through UC00A, meanwhile the function of 'Convert' button was used to automatically convert the output (kHz) received from PIC to blood glucose concentration value (mmol/L) according to the set equation.

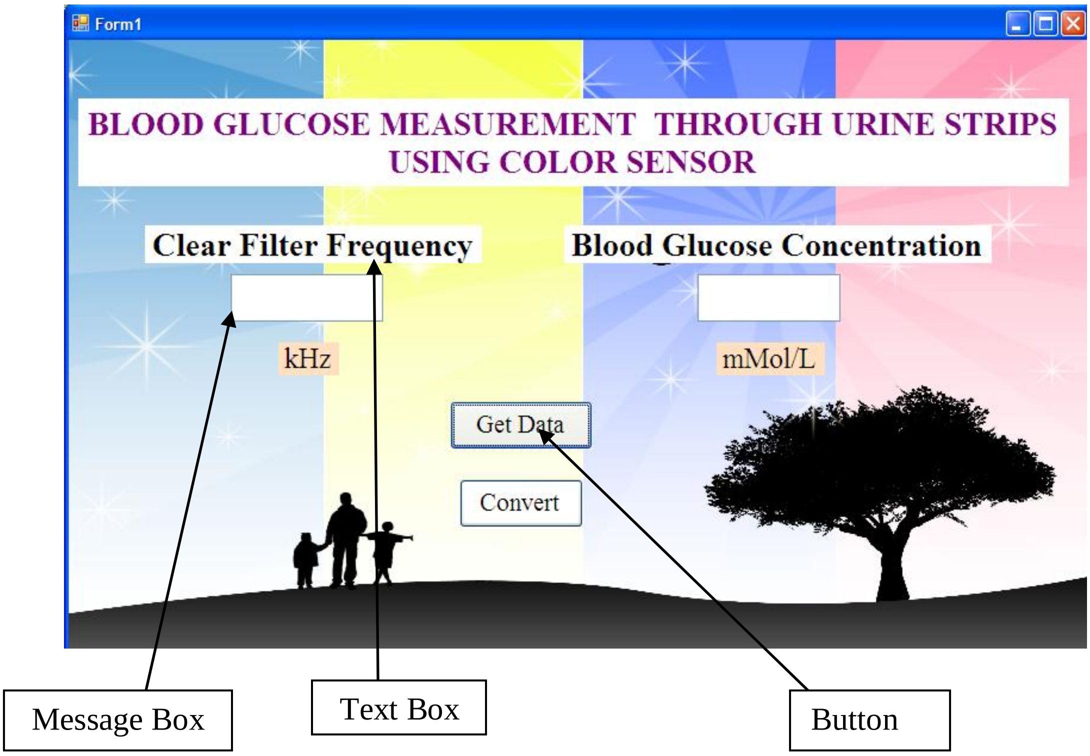

Figure 3.13 Form 1

3.4 Hardware and Software Implementation

Figure 3.14 illustrates the overall system for blood glucose measurement through urine strip using a photosensor. The input of photosensor was selected according to desired filter by switching the two switches on the photosensor box. Then the output (kHz) of the photosensor was transferred into PIC18F452 and the value of the output was digitalized by the microcontroller. After that, the output value was displayed by the GUI window through a UC00A (USB Converter). These overall systems model implemented due to performance testing and in term of troubleshooting to improve the accuracy and quality of the measurement.

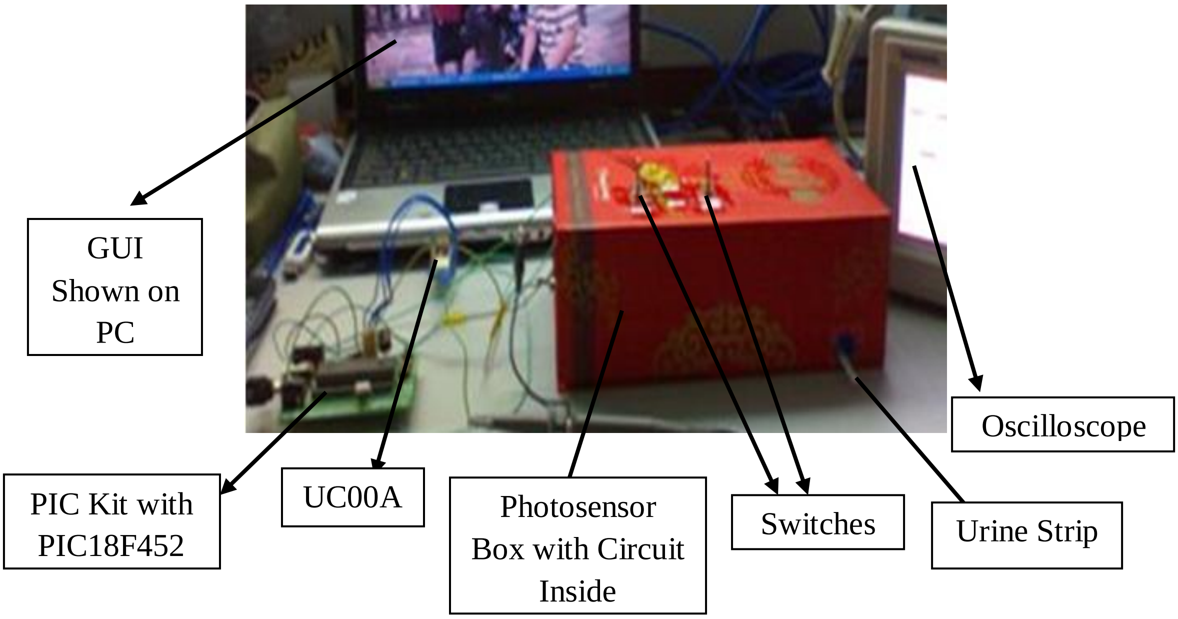

Figure 3.14 The Overall System

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

This chapter discussed the testing, results and analysis of the system. I tested the functionality of the photosensor first before I started the main testing on samples. The sample testing had taken a long time to be completed. Then, the data collected were plotted on graph for further analyzed. After that, analysis had been made based on the testing results.

4.2 Testing the Functionality of the Photosensor

Figure 4.1 shows block diagram to test the functionality of photosensor using different color papers.

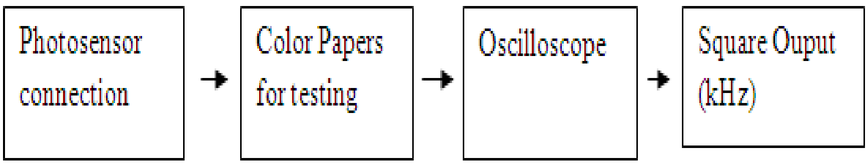

Figure 4.1 Block Diagram to Test the Functionality of Photosensor

4.2.1 Procedures

i. The experiment was set up as Figure 4.1.
ii. The input supply voltage must set to less than 5.5V for the pin 1 and 2 of the photosensor.
iii. The LED input voltage must set to less than 3.9V at pin 5 of photosensor.
iv. A square wave form output signal of photosensor was obtained from the oscilloscope before testing.
v. Papers with different types of color were prepared for each testing.
vi. The input from the switches was selected and each color paper with 4 different variable inputs was tested.
vii. Outputs (in kHz) of photosensor can be taken from oscilloscope.
viii. Steps 4, 5, 6 and 7 were repeated for different color paper with 4 different types of inputs from the photosensor.

Figure 4.2 shows the square wave output signal (kHz) of the photosensor taken from oscilloscope. From the testing results obtained, it can be concluded that the photosensor is functioning well and outputs obtained for each color paper with 4 different variable inputs were within the specifications of the photosensor as stated in datasheet there. The photosensor can only be used for further urine samples testing after being tested successfully.

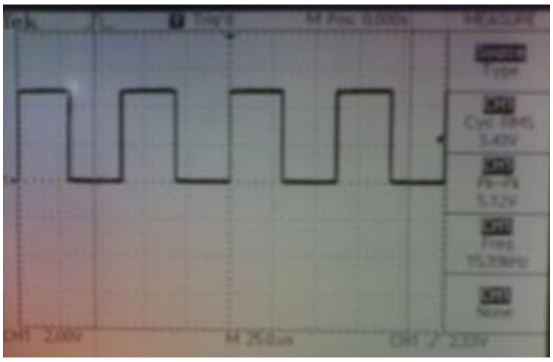

Figure 4.2 Output Signal (kHz) of the Photosensor

4.3 Samples Collection and Testing

The whole samples testing process was taken at Pusat Kesihatan UTM as both the blood and urine sample were needed for every patient. The blood sample collection was done by laboratory staff and the blood samples were tested using a Roche 902 blood analyzer as shown in figure 4.3. At the same time, urine sample was taken for the same person and it was tested using the photosensor.

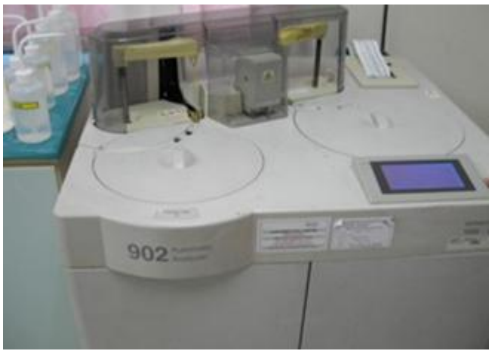

Figure 4.3 Roche 902 Blood Analyzer

4.4 Results Obtained From Samples Testing

Total of 42 patients being tested and their urine and blood samples were collected and tested. Results obtained from the blood analyzer and oscilloscope collected and then being put into Microsoft Excel for further analysis. Graphs were plotted based on the results obtained for these four different inputs of the photosensor.

4.4.1 For Red Filter Selected As Input of Photosensor

Figure 4.4 shows the graph of blood glucose concentration values (mmol/L) versus the outputs (kHz) from the photosensor with red filter selected as an input. A linear relationship was obtained with an equation of y = -0.6809x + 19.616.

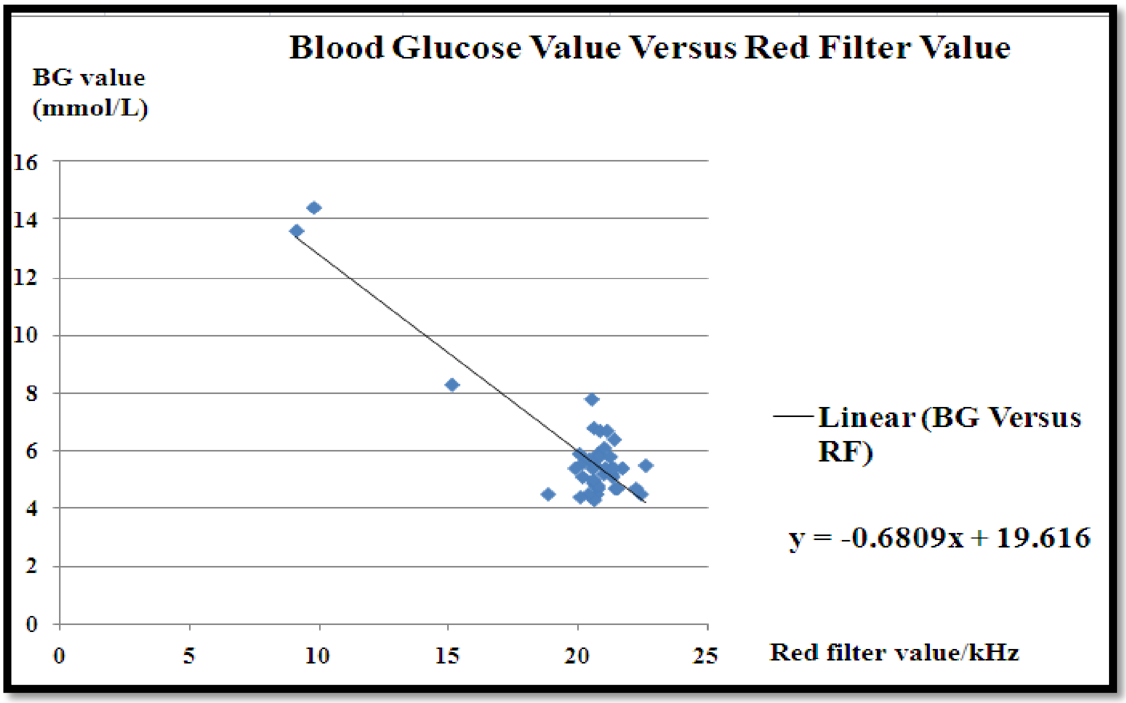

Figure 4.4 Graph of Blood Glucose Value (mmol/L) versus Red Filter Output Value (kHz)

4.4.2 For Green Filter Selected As Input Of Photosensor

Figure 4.5 shows the graph of blood glucose concentration values (mmol/L) versus the outputs (kHz) from the photosensor with green filter selected as an input. A linear relationship was obtained with an equation of y = -0.5739x + 21.61.

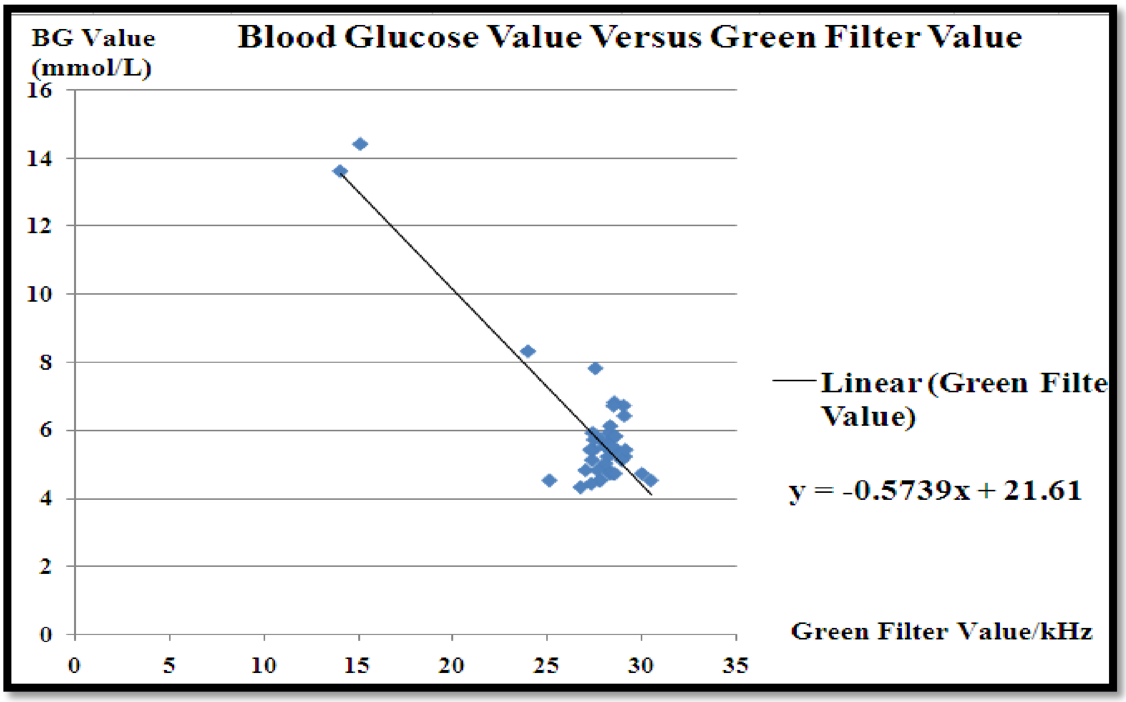

Figure 4.5 Graph of Blood Glucose Value (mmol/L) versus Green Filter Output Value (kHz)

4.4.3 For Blue Filter Selected As Input Of Photosensor

Figure 4.6 shows the graph of blood glucose concentration values (mmol/L) versus the outputs (kHz) from the photosensor with blue filter selected as an input. A linear relationship was obtained with an equation of y= -0.9301x + 24.899.

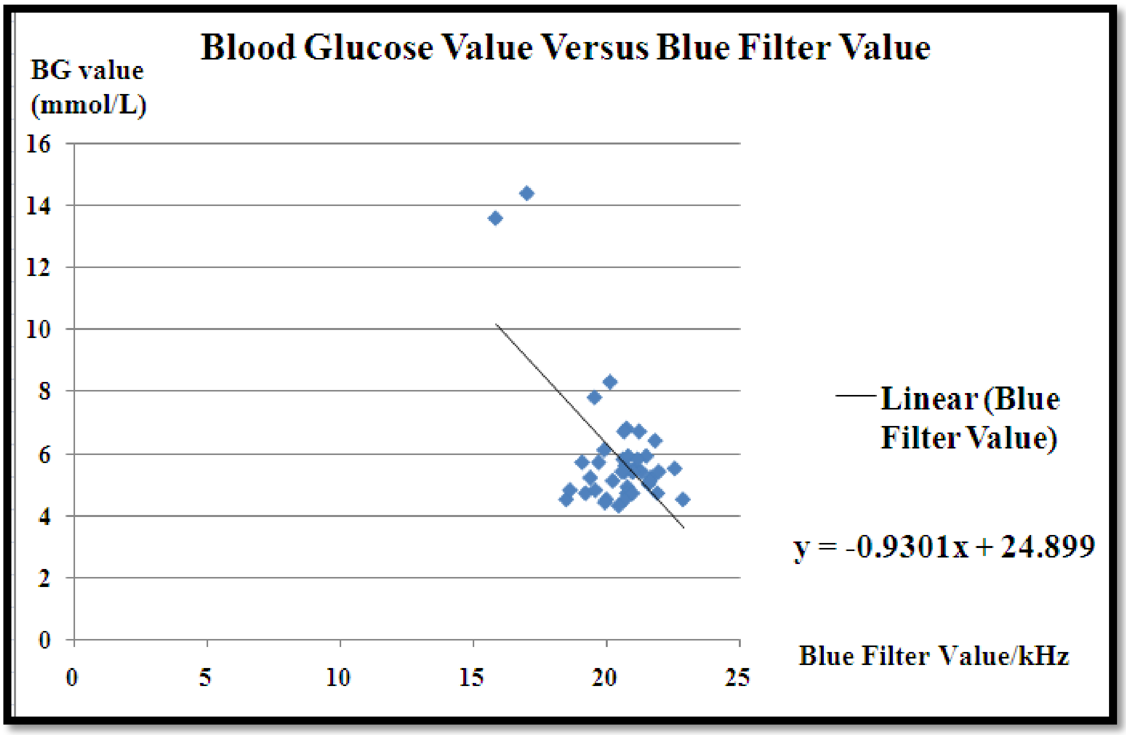

Figure 4.6 Graph of Blood Glucose Value (mmol/L) versus Blue Filter Output Value (kHz)

4.4.4 For Clear Filter Selected As Input Of Photosensor

Figure 4.7 shows the graph of blood glucose concentration values (mmol/L) versus the outputs (kHz) from the photosensor with clear filter selected as an input. A linear relationship was obtained with an equation of y= -0.2034 x + 22.497.

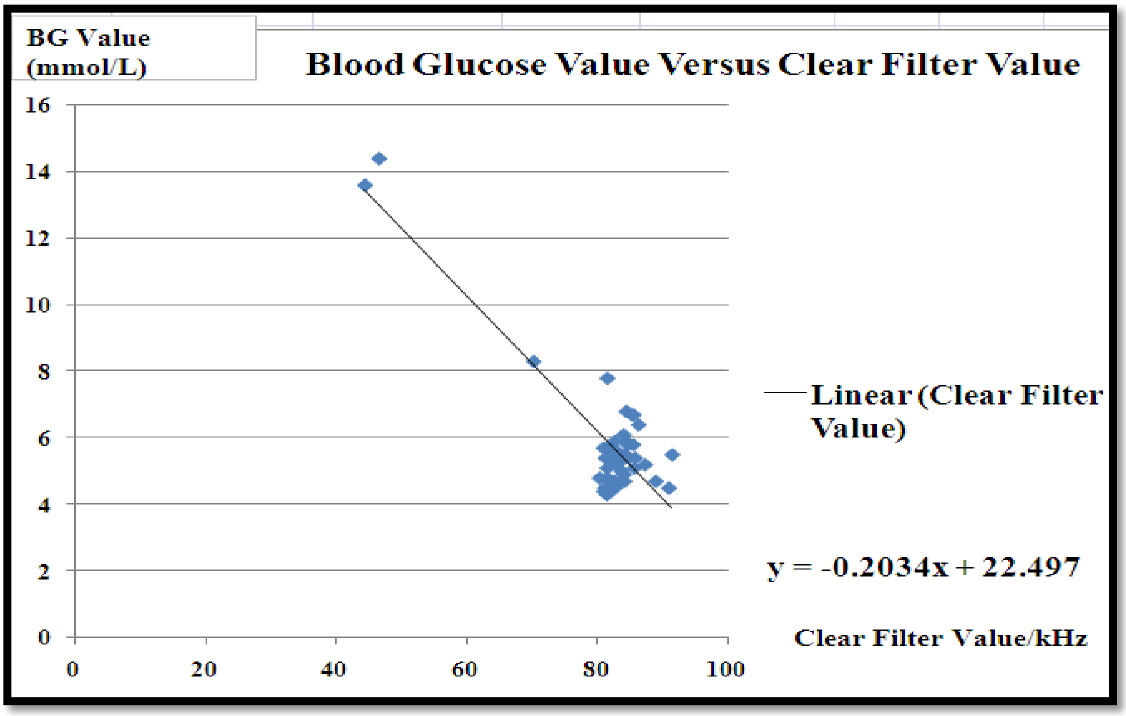

Figure 4.7 Graph of Blood Glucose Value (mmol/L) versus Clear Filter Output Value (kHz)

4.5 Discussions

The results obtained from a total of 42 patients were analyzed and summarized as shown in Table 4.1. Since there were four different types of inputs that can be selected from the photosensor and i determined and fixed the considered most accurate filter as our input for our future blood glucose measurement.

Clear filter was selected to be the fixed input for future blood glucose measurement as it had the least absolute maximum error which was only 1.1348 compared to other filters. The smaller the value of absolute maximum error, the smaller deviation of calculated blood glucose value from the output of photosensor with the value obtained from the blood glucose analyzer machine. So, the more accurate of the result obtained from the selected clear filter as input.

Besides that, it's only 0.064 difference of mean error between the clear filter and red filter (least mean error value). It showed that not much different for the mean error of clear filter with other filters. These were the reasons why clear filter was selected as a fixed input and its linear equation of y= -0.2034 x + 22.497 were used for software programming including PIC Programming and GUI using VB.NET as well.

Table 4.1 : Result Analysis

Data Analysis / Input Selection	Total Error = ∑(Blood glucose value from machine- Blood glucose value from graph) mmol/L	Mean Error = Total Error/42	Absolute Max Error = |mean error- max error|	Absolute Min Error = |mean error- min error|
Red Filter	29.1267	0.6935	1.5508	0.6883
Green Filter	30.9576	0.7371	1.9451	0.7262
Blue Filter	49.4749	1.1780	4.1440	1.1728
Clear Filter	31.8142	0.7575	**1.1348**	0.7508

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter described the conclusion and the recommendation of this project

5.1 Conclusion

An instrument used to measure blood glucose concentration value through urine strip using a photosensor has been developed. This system consists of photosensor circuit, analog to digital converter, serial port interface and graphical user interface. This measurement range for blood glucose concentration value in this system is from 0 to 22 mmol/L.

5.2 Recommendation

Although this project is successfully developed and met the objective, however it is found that this system can be further improved by integrating it into mobile medical system such as PDA.

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APPENDIX A

UCOOA (USB to UART Converter)

Features:

This development offer low cost, easy to use USB to UART converter to user.

It has been designed with capabilities and features of:

• Develop low cost USB to UART converter

• Easy to use USB to UART converter, aiming development between computer and microcontroller, 5V logic.

• USB powered, no external source is required to use this converter

• 5V from USB port is available for user.

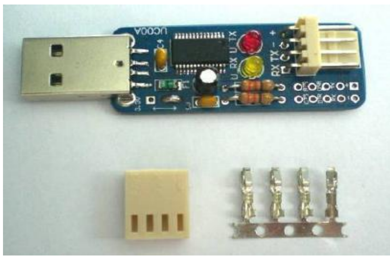
• Configurable for 5V UART interface.

• Easy to use 4 pin interface: Tx, Rx, Gnd and 5V.

• CTS, RTS, DTR and DSR is pull out to standard 2x5 header pin solder able PCB pad.

• Plug and Play

Packing List:

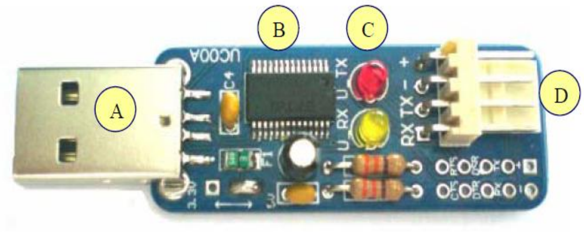


1. 1 x UC00A.

2. 1 x 2510 4 ways connector.

3. 4 x 2510 iron pins.

4. USB driver and User's Manual should be downloaded from Cytron Website.



Label	Function
A	USB A type (male).
B	USB to UART chip.
C	Two LED indicators for USB's transmitter and receiver status.
D	4 ways header pin for interface to microcontroller.

Cautions: "+" on UC00A is 5V supply directly from USB port of computer; it is advised not to use this power source to power application circuit or device. Wrong connection such as wrong polarity, wrong voltage, shorted might permanently damage computer.

UC00A is designed to ease communication between microcontroller and PC. The specifications are as listed below:

Pin	Label	Definition	Function
1	+	5V Power output from UC00A	5V supply from USB, optional for user to power external device, maximum current 200mA.
2	–	Ground or negative	Ground of power and signal. This pin should be connected to device's GND pin.
3	TX	UC00A UART Transmit signal	This is UC00A's transmitter pin (5V TTL). It should be connected to device's receiver pin.
4	RX	UC00A UART Receive signal	This is UC00A's receiver pin (5V TTL). It should be connected to device's transmitter pin.

Absolute Maximum Rating

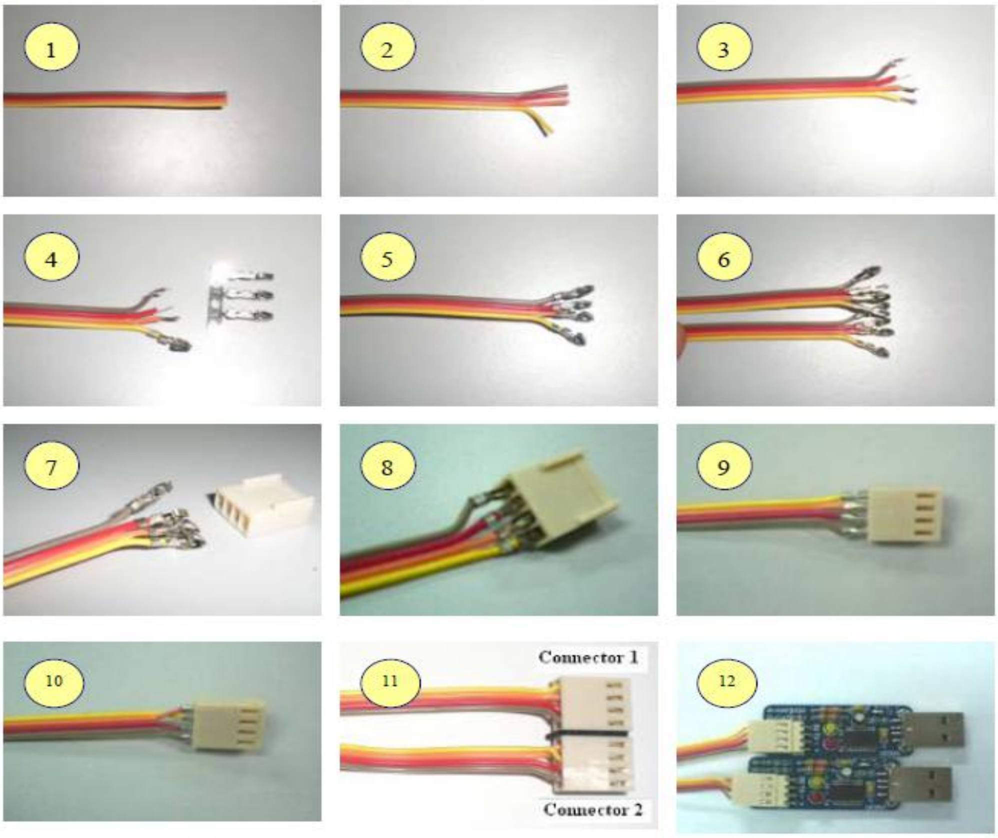
Symbol	Parameter	Min	Max	Unit
+	Power output pin	5.0	5.0	V
-	Operating voltage	0	0	V
TX	Transmitter pin of UC00A	0	5.5	V
RX	Receiver pin of UC00A	0	5.5	V

Software Installation

UC00A used USB to UART chip and it require USB driver to be installed (1 time) on computer. Thus, this section, user may refer to document name "Windows XP Installation Guide" which provides users a simple procedure for installing drivers for this device driver under Windows XP.

Hardware Installation

For interface with hardware or microcontroller, user needs a cable to plug between UC00A and hardware. Below are the picture and method of making 4 ways cable. For step 6, repeat step 1 to 5 for the other end of cable. Please start with the same side done in step (yellow on bottom and the iron pin is facing up). For step 10 (second side of cable), nodes in pin 1 and 2 are switch with first side.


1
2
3
4
5
6
7
8
9
10
11
Connector 1
Connector 2
12

APPENDIX B

SK40C ENHANCED 40 PINS PIC START-UP KIT

Features:

 Industrial grade PCB

 Compact, powerful, flexible and robust start-up platform

 Save development and soldering time

 No extra components required for the PIC to function

All 33 I/O pins are nicely labeled to avoid miss-connection by users

Connector for UIC00A (low cost USB ICSP PIC Programmer) - simple and fast method to load program

 No more frustrated work plugging PIC out and back for re-programming

 Perfectly fit for 40 pins16F and PIC18F PIC

 With UIC00A, program can be loaded in less than 5 seconds

 Maximum current is 1A.

Dimension: 85mm x 55mm

 2 x Programmable switch

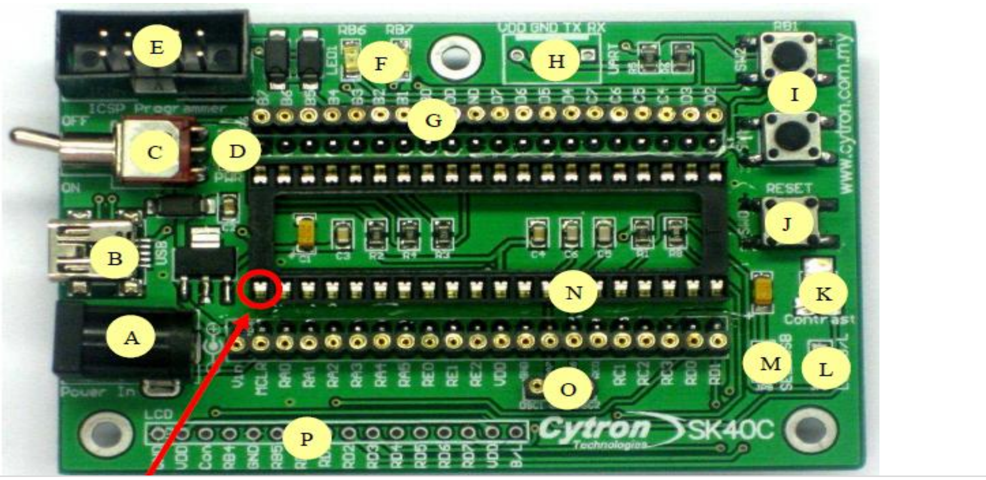
 2 x LED indicator

 Turn pin for crystal. User may use others crystal provided.

 LCD display (optional)

UART communication

 And all the necessities to eliminate users difficulty in using PIC



Label	Function	Label	Function
A	DC power adaptor socket	I	Programmable Push Button
B	USB Connector	J	Reset button
C	Toggle Switch for power supply	K	LCD contrast
D	Power indicator LED	L	JP8 for LCD Backlight
E	Connector for UIC00A Programmer	M	JP9 for USB
F	LED Indicator	N	40 pin IC socket for PIC MCU
G	Header pin and turn pin	O	Turn pin for crystal
H	UART Connector	P	LCD Display

Note: Only 1 power supply should be provided to SK40C.

Figure below shown pin connection for **'Label P'** (2x16 LCD Display).

Pin	Name	Pin function	Connection
1	GND	Ground	GND
2	VDD	Positive supply for LCD	5V
3	Con	Brightness adjust	Connected to a preset to adjust brightness
4	RB4	Select register, select instruction or data register	Pin RS of LCD
5	GND	Ground	GND
6	RB5	Start data read or write	Pin E of LCD
7	RD0	LCD Data bus pin	Pin D0 of LCD
8	RD1	LCD Data bus pin	Pin D1 of LCD
9	RD2	LCD Data bus pin	Pin D2 of LCD
10	RD3	LCD Data bus pin	Pin D3 of LCD
11	RD4	LCD Data bus pin	Pin D4 of LCD
12	RD5	LCD Data bus pin	Pin D5 of LCD
13	RD6	LCD Data bus pin	Pin D6 of LCD
14	RD7	LCD Data bus pin	Pin D7 of LCD
15	VDD	Backlight positive input	VDD
16	B/L	Backlight negative input	Connect to JP8

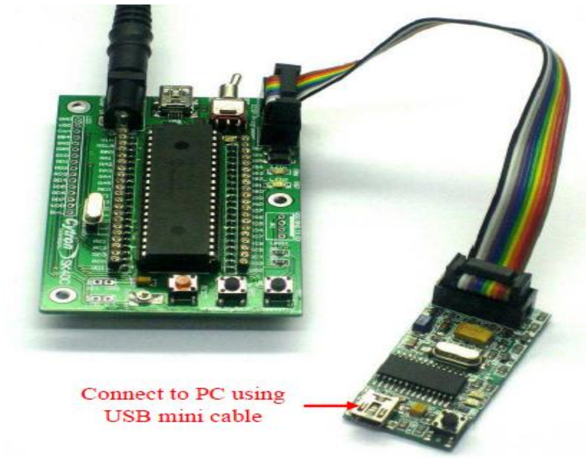
Absolute Maximum Rating

Symbol	Parameter	Min	Max	Unit
V_{CC}	Operating voltage	7	15	V
I_{max}	Maximum input current	-	1	A

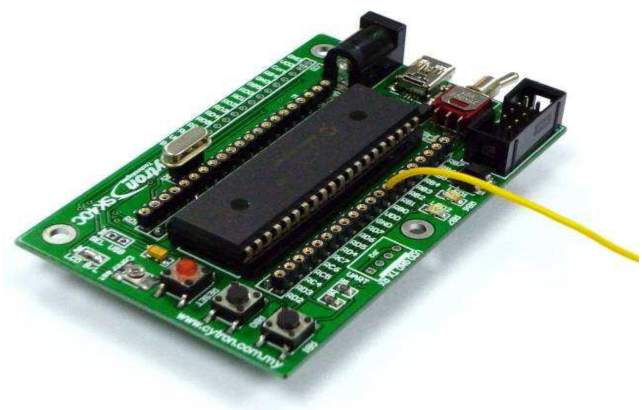
INSTALLATION (HARDWARE)

SK40C come with UIC00A USB programmer connector to offer simple way for downloading program.UIC00A programmer is very easy and save plenty of development time.

Loading Program Using UIC00A Programmer

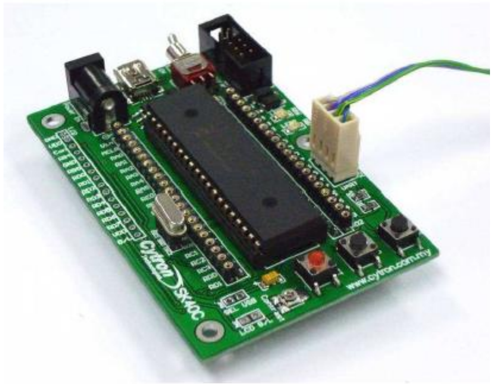


After plug in 40 pin PIC MCU (make sure the orientation is correct), SK40C should be powered by DC adaptor. Now, the hex code is ready to be loaded to SK40C. Extend the I/O port to another board using jumper wire as below:

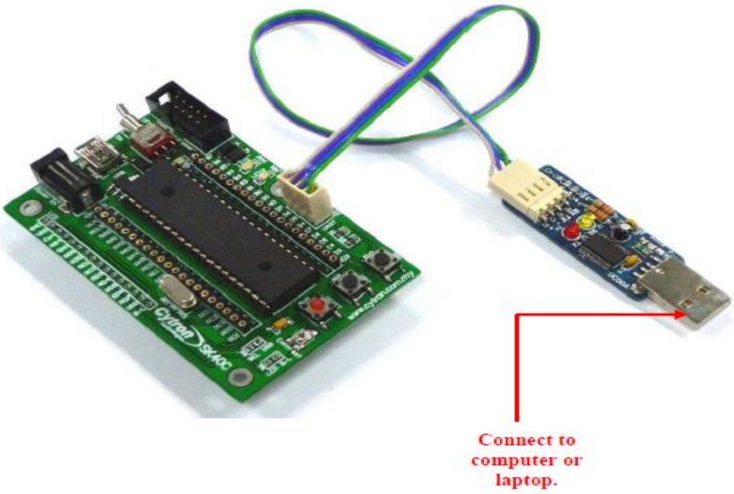


For UART Interface Connections:

Connect to other microcontroller using cable connector



Connect to computer/laptop using UC00A (communication between SK40C and PC)



APPENDIX C

DATA SHEET OF REFLECTIVE COLOR SENSOR ASSEMBLE (OPB780Z)

Features:

- High-resolution conversion of light intensity to frequency
- Selectable color output frequency
- Communicates directly with a microcontroller
- Sensor power supply operation (2.7 V to 5.5 V)
- LED power separate input
- Includes LED, Sensor and interface cable

Description:

The OPB780Z colour sensor uses a light-to-frequency converter that combines 64 configurable silicon photodiodes (on a 144 um centre and measuring 120 um x 120 um each), with a white LED in a small, lightweight package that makes it ideal for using in miniature applications. The output is a square wave (50% duty cycle) with a frequency directly proportional to reflected light intensity (irradiance). The light-to-frequency converter reads an 8 x 8 array of photodiodes that consists of four groups of 16 photodiodes each, segregated by colour: 16 photodiodes with red filters, 16 photodiodes with green filters, 16 photodiodes with blue filters and 16 clear photodiodes with no filters. Each colour's group of 16 photodiodes is inter-digitized to minimize the effect of non-uniformity of the incident irradiance. Each colour's group is also connected in parallel. The type of photodiode used during operation is pin-selectable. The output of the device is designed to drive a standard TTL or CMOS logic input over short distances. The internal photodiode used by the device is controlled by two logic inputs, S2 and S3.

Applications:

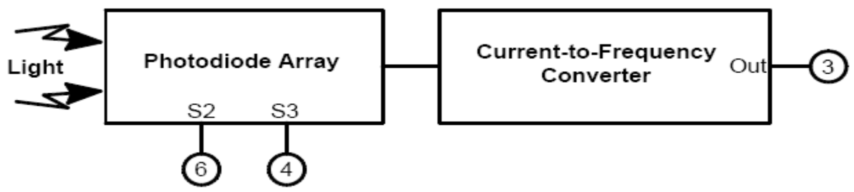
- Photographic equipment
- Colormetry

• Chemical analyzers

• Display contrast controls

• High resolution digital measurement of light intensity

Block Diagram



Ordering Information	
OPB780Z	OPB780 with 10" Long Flat Flex Cable
KA3128	10" Long Flat Flex Cable

Absolute Maximum Ratings[1, 2] (T_A = 25° C unless otherwise noted)

Operating Temperature	T_{OPR} = -30° C to +85° C
Storage Temperature	T_{STG} = -30° C to +85° C

LED—Absolute Maximum Ratings[1, 2] (T_A = 25° C unless otherwise noted)

Reverse Voltage	V_R = 5 V
Forward Current	I_F = 30 mA
Power Dissipation	P_D = 120 mW
Peak Forward Current	I_{FP} = 100 mA

Sensor—Absolute Maximum Ratings[1, 2] (over operating free-air temperature range unless otherwise noted)

Supply Voltage(V_{DD})	6 V
Input Voltage (all inputs, V_I)	-0.3 V to V_{DD} + 0.3 V

Notes:

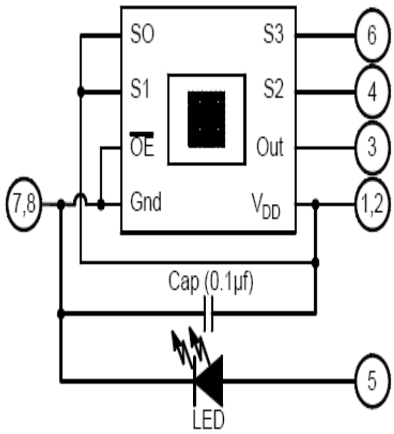
(1) *Stresses beyond those linked under "absolute maximum rating" may cause permanent damage to device.* These are only stress ratings, and functional operating of the device at these (or any other) conditions beyond those indicated in the

Recommended Operating Conditions table shown above may affect the device's reliability.

(2) All voltage values are with respect to GND.

(3) Full-scale frequency is the maximum operating frequency of the device without saturation.

(4) Output interface of device is designed to drive a standard TTL or CMOS logic input over short distances. If lines greater than 12 inches are used on output, a buffer or line driver is recommended.



Pin Name	Pin #	Description
V_{DD}	1, 2	Supply voltage
OUT	3	Output Frequency (F_O)
S2	4	Photodiode type selection input
LED Anode	5	LED input
S3	6	Photodiode type selection input
GND	7, 8	Power supply ground

LED

Electro-Optical Characteristics of LED[1] (T_A = 25°C unless otherwise noted) (See OVLAW4CB7 for more info.)

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
$I_V^{(1)}$	Luminous Intensity	-	1.0	-	cd	I_F = 20 mA
V_F	Forward Voltage	2.8	3.4	3.9	V	I_F = 5 mA
I_R	Reverse Current	-	-	10	µA	V_R = 5 V

Sensor

Recommended Operating Conditions[1]

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	RECOMMENDED CONDITIONS
V_{DD}	Supply Voltage	2.7	5	5.5	V	-
V_{IH}	High-Level Input Voltage	2.0	-	V_{DD}	V	V_{DD} = 2.7 V to 5.5 V
V_{IL}	Low-Level Input Voltage	0.0	-	0.8	V	V_{DD} = 2.7 V to 5.5 V
T_A	Operating Free-Air Temperature Range	-40	-	+70	°C	-

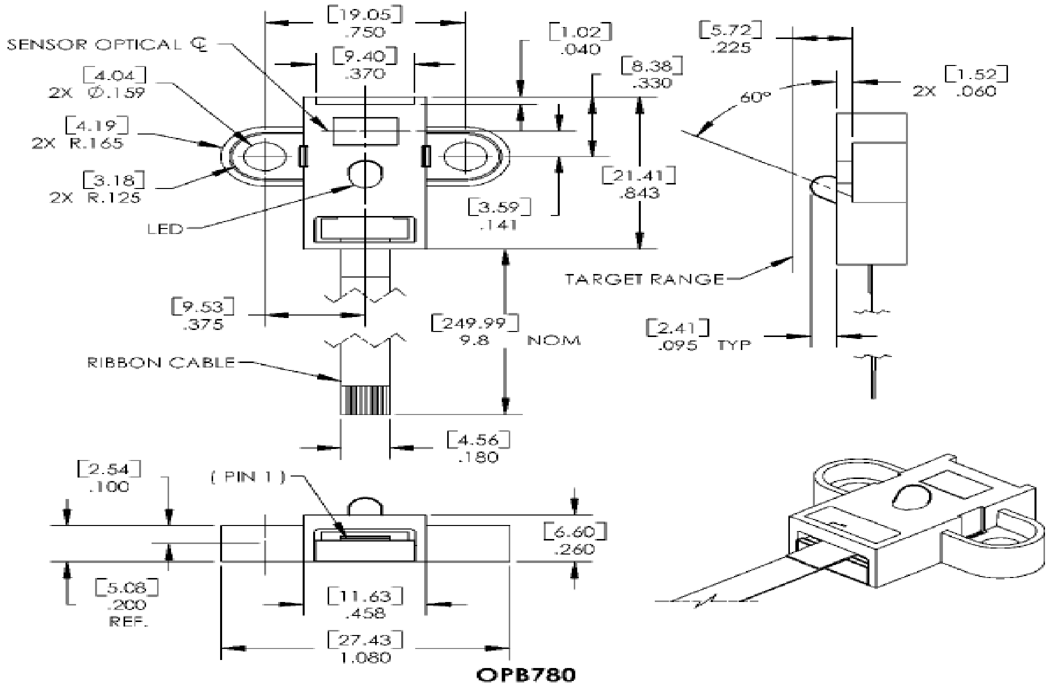
Sensor

Electrical Characteristics[1] (T_A = 25° C, V_{DD} = 5 V unless otherwise noted)

SYMBOL	PARAMETER	MIN	TYP	MAX	UNITS	TEST CONDITIONS
V_{OH}	High-Level Output Voltage [3]	-	4.5	-	V	I_{OH} = -4 mA
V_{OL}	Low-Level Output Voltage [3]	-	0.25	-	V	I_{OL} = 4 mA
I_{IH}	High-Level Input Current	-	-	5	µA	-
I_{IL}	Low-Level Input Current	-	-	5	µA	-
I_{DD}	Supply Current	-	2	3	mA	Power on
-	Full-Scale Frequency [2]	-	600	-	kHz	-
-	Temperature Coefficient of Output Frequency	-	±200	-	ppm/°C	λ ≤ 700 nm, -25° C ≤ T_A ≤ 70° C / ± 200 ppm/° C
t_r, t_f	Typical Temperature Rise Time Typical Temperature Fall Time	-	100	-	µ sec.	-

Output Frequency Characteristics[1]
(VDD = 5 V, T_A = 25 °C, I_F = 5mA)

Target / Surface	Minimum	Maximum	Units
Red Filter Selected (S2=L/S3=L)			
Red	23	41	kHz
Green	7	15	
Blue	3	7	
White	-	1.5	
Green Filter Selected (S2=H/S3=H)			
Red	6	15	kHz
Green	6	37	
Blue	5	13	
White	-	1.5	
Blue Filter Selected (S2=L/S3=H)			
Red	4	23	kHz
Green	13	21	
Blue	21	36	
White	-	1.5	
Clear Filter Selected (S2=H/S3=L)			
Red	38	71	kHz
Green	46	85	
Blue	31	60	
White	-	5	



Target Range = 0.225 inch= 0.5715cm

APPENDIX D

Full Source Codes of PIC 18F452 Microcontroller

```
LIST P=18F452              ;directive to define processor
#include <P18F452.INC> ;processor specific variable definitions
;   Oscillator Selection:
   CONFIG        OSC = HS           ; LP
   CONFIG        BOR = OFF
   CONFIG        WDT = OFF
   CONFIG        LVP = OFF
   CONFIG        PWRT = ON
CONFIG           OSCS = OFF

; Variable definitions
; These variables are only needed if low priority interrupts are used.
; More variables may be needed to store other special function registers used
; in the interrupt routines.
CBLOCK      0x080
WREG_TEMP    ;variable used for context saving
STATUS_TEMP ;variable used for context saving
BSR_TEMP       ;variable used for context saving
ENDC
CBLOCK      0x000
EXAMPLE                    ;example of a variable in access RAM
d1
d2
d3
STORE1
STORE2
STORE3
VAR920US
NumH
NumL
TenK
Thou
Hund
Tens
Ones
ENDC

;EEPROM data
; Data to be programmed into the Data EEPROM is defined here
ORG      0xf00000
DE       "Test Data",0,1,2,3,4,5

;Reset vector
; This code will start executing when a reset occurs.
ORG      0x0000
goto     Main                 ;go to start of main code

;High priority interrupt vector
; This code will start executing when a high priority interrupt occurs or
; when any interrupt occurs if interrupt priorities are not enabled.
ORG      0x0008
bra      HighInt              ;go to high priority interrupt routine

;Low priority interrupt vector and routine
; This code will start executing when a low priority interrupt occurs.
; This code can be removed if low priority interrupts are not used.
ORG      0x0018
movff    STATUS,STATUS_TEMP ;save STATUS register
movff    WREG,WREG_TEMP       ;save working register
movff    BSR,BSR_TEMP         ;save BSR register
```

```
; low priority interrupt code goes here
movff                                   BSR_TEMP,BSR                ;restore BSR register
movff                                   WREG_TEMP,WREG      ;restore working register
movff                                   STATUS_TEMP,STATUS ;restore STATUS register
                    retfie
;High priority interrupt routine
; The high priority interrupt code is placed here to avoid conflicting with
; the low priority interrupt vector.

HighInt:

;high priority interrupt code goes here
retfie      FAST

;Start of main program
; The main program code is placed here.
Main:

; main code goes here
CLRF PORTB ; Initialize PORTB by

; clearing output
; bsf       STATUS, RPO
; data latches
CLRF LATB ; Alternate method

; to clear output
; data latches
MOVLW 0x08 ; Value used to initialize data
; direction
MOVWF TRISB ; Set RB<3:0> as inputs
; RB<5:4> as outputs
; RB<7:6> as inputs
bcf         TRISC,6
bsf         TRISC,7
clrf        TenK
clrf        Thou
clrf        Hund
clrf        Tens
clrf        Ones

; goto      testloc
movlw       0x081           ; before send serial com, init with this
movwf       SPBRG
bsf                 RCSTA,SPEN
movlw       0x080
movwf       RCSTA
movlw       0x0A4
movwf       TXSTA

XYZ
bsf                 RCSTA,CREN
btfss       PIR1,RCIF
goto        XYZ             ;back1
movf        RCREG,w

ABC
clrf        NumL
clrf        NumH
```

```
cntloopA
 btfsc  PORTB,3
 goto   cntloopA              ;da start kire ;kire semasa high

cntloop
 btfss  PORTB,3
 goto   cntloop               ;da start kire ;kire semasa high

cntloop1
 incf     NumL,f                          ;1 / 1
 btfsc    STATUS,Z                        ;2 / 1
 incf     NumH,f                  ;0 / 1
 btfsc  PORTB,3 ; looping 1 cycle, exit loop 2 cycle
 goto   cntloop1   ; 2 cycle

cntloop2                          ;kire semasa low
 incf     NumL,f                          ;1 / 1
 btfsc    STATUS,Z                        ;2 / 1
 incf     NumH,f                  ;0 / 1
 btfss  PORTB,3                                             ;da stop kire
 goto   cntloop2

movlw   0x081    ; before send serial com, init with this
movwf   SPBRG
bsf                 RCSTA,SPEN
movlw   0x080
movwf   RCSTA
movlw   0x0A4
movwf   TXSTA

back1
movlw   0x80
movwf   PORTB
movf    TenK,w
addlw   0x30
movwf   TXREG
movlw   0x40
movwf   PORTB
call    DELAY

back2
movf    RCREG,w
movlw   0x80
movwf   PORTB
movf    Thou,w
addlw   0x30
movwf   TXREG
movlw   0x40
movwf   PORTB
call    DELAY

back3
movf    RCREG,w
movlw   0x80
movwf   PORTB
movf    Hund,w
addlw   0x30
movwf   TXREG
movlw   0x40
```

```
movwf   PORTB
call    DELAY

back4
movf    RCREG,w
movlw   0x80
movwf   PORTB
movf    Tens,w
addlw   0x30
movwf   TXREG
movlw   0x40
movwf   PORTB
call    DELAY

back5
movf    RCREG,w
movlw   0x80
movwf   PORTB
movf    Ones,w
addlw   0x30
movwf   TXREG
movlw   0x40
movwf   PORTB
call    DELAY
goto    XYZ

Loop
btfsc   PORTB,1
goto    ONN
goto    OFF

ONN
movlw   0xC0
movwf   PORTB
goto    Loop

OFF
movlw   0x00
movwf   PORTB
goto    Loop

DELAY

movlw   1
movwf   d3

LPD3
movlw   10
movwf   d2

LPD2
movlw   57
movwf   d1

LPD1
decfsz d1,f
goto    LPD1
decfsz  d2,f
goto    LPD2
decfsz  d3,f
```

```
goto      LPD3
return

DELAY2                    ;4ms selang atr beat
MOVLW          10
MOVWF          STORE2

LP2
MOVLW          131
MOVWF          STORE1

LP
DECFSZ         STORE1, F
GOTO   LP
DECFSZ         STORE2, F
GOTO   LP2

RETURN

;SUBROUTINE HEX to DECIMAL
H2d:                              ; Takes number in NumH:NumL

; Returns decimal in
; TenK:Thou:Hund:Tens:Ones
swapf     NumH, w
iorlw     B'11110000'
movwf   Thou
addwf    Thou,f
addlw     0XE2
movwf   Hund
addlw    0X32
movwf   Ones
movf      NumH,w
andlw     0X0F
addwf    Hund,f
 addwf   Hund,f
addwf    Ones,f
addlw    0XE9
movwf   Tens
addwf    Tens,f
addwf    Tens,f
swapf     NumL,w
andlw    0X0F
addwf    Ones,f
rlcf       Tens,f
rlcf       Ones,f
comf      Ones,f
rlcf       Ones,f
movf       NumL,w
andlw     0X0F
addwf     Ones,f
rlcf        Thou,f
movlw    0X07
movwf   TenK

; At this point, the original number is equal to
: TenK*10000+Thou*1000+Hund*100+Tens*10+Ones
; if those entities are regarded as two's complement binary. To be precise, all of
; them are negative except TenK. Now the number needs to be normalized, but this can
; all be done with simple byte arithmetic.
```

```
movlw   0X0A                    ; Ten

Lb1:
decf     Tens,f
addwf    Ones,f
btfss    STATUS,C
goto      Lb1

Lb2:
decf      Hund,f
addwf    Tens,f
btfss    STATUS,C
goto     Lb2

Lb3:
decf      Thou,f
addwf     Hund,f
btfss     STATUS,C
goto      Lb3

Lb4:
decf     TenK,f
addwf     Thou,f
btfss    STATUS,C
goto      Lb4
retlw    0x00

;           END SUBROUTINE HEX to DECIMAL
;End of program
END
```

APPENDIX E

Full Source Code of Graphical User Interface (GUI) in VB.NET

FORM 1

```
Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button1.Click
    Dim mmol As String
    Dim freq As Double
    Dim yO As Double
    Dim rxdata(5) As Byte

    Dim dataSer As Byte
    Dim Total As Integer
    Dim c As String

    SerialPort1.DiscardInBuffer()
    SerialPort1.Write("A")
    'SerialPort1.Read(rxdata, 0, 5)
    'dataSer = SerialPort1.ReadByte()
    'TextBox3.Text = ChrW(dataSer)

    'dataSer = SerialPort1.ReadByte()
    'TextBox1.Text = ChrW(dataSer)
    'SerialPort1.Read(rxdata, 0, 5)

    'dataSer = SerialPort1.ReadByte()
    'dataSer = rxdata(1)
    'TextBox3.Text = ChrW(dataSer)
    'TextBox4.Text = ChrW(rxdata(2))

    'SerialPort1.Write("A")
    'dataSer = SerialPort1.ReadByte()
    'TextBox1.Text = ChrW(dataSer)

    'SerialPort1.Write("A")
    'dataSer = SerialPort1.ReadByte()
    'TextBox1.Text = ChrW(dataSer)

    'SerialPort1.Write("A")
    'dataSer = SerialPort1.ReadByte()
    'TextBox1.Text = ChrW(dataSer)

    'SerialPort1.Write("A")
    'dataSer = SerialPort1.ReadByte()
    'TextBox1.Text = ChrW(dataSer)

  End Sub

  Private Sub Label3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Label3.Click

  End Sub

  Private Sub TextBox2_TextChanged(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles TextBox2.TextChanged

  End Sub

  Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
    SerialPort1.Close()
  End Sub
```

```
    Private Sub Button4_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles Button4.Click
        Dim mmol As String
        Dim freq As Double
        Dim yO As Double
        Dim rxdataq(5) As Byte
        Dim tenthou As Double
        Dim thou As Double
        Dim hund As Double
        Dim ten As Double
        Dim one As Double
        Dim HzValue As Double
        Dim HzStr As String
        Dim timeCount As Double

        SerialPort1.Read(rxdataq, 0, 5)
        TextBox3.Text = ChrW(rxdataq(0))
        TextBox4.Text = ChrW(rxdataq(1))
        TextBox5.Text = ChrW(rxdataq(2))
        TextBox6.Text = ChrW(rxdataq(3))
        TextBox7.Text = ChrW(rxdataq(4))

        tenthou = Conversion.Val(TextBox3.Text)
        thou = Conversion.Val(TextBox4.Text)
        hund = Conversion.Val(TextBox5.Text)
        ten = Conversion.Val(TextBox6.Text)
        one = Conversion.Val(TextBox7.Text)

        timeCount = tenthou * 10000 + thou * 1000 + hund * 100 + ten * 10 + one
        HzValue = (1 / (timeCount * 0.0000011875)) / 1000
        HzStr = Conversion.Str(HzValue)
        TextBox1.Text = HzStr

        freq = Conversion.Val(TextBox1.Text)
        'yO = (-1) * 0.2034 * freq + 22.497
        yO = 22.497 - 0.2034 * freq
        mmol = Conversion.Str(yO)
        TextBox2.Text = mmol

    End Sub

    Private Sub Form1_Deactivate(ByVal sender As Object, ByVal e As System.EventArgs) Handles
Me.Deactivate

    End Sub

    Private Sub Form1_Leave(ByVal sender As Object, ByVal e As System.EventArgs) Handles
Me.Leave
        SerialPort1.Close()
    End Sub

    Private Sub Form1_Load(ByVal sender As Object, ByVal e As System.EventArgs) Handles
Me.Load
        SerialPort1.Open()
    End Sub

    Private Sub Form1_Shown(ByVal sender As Object, ByVal e As System.EventArgs) Handles
Me.Shown
    End Sub
End Class
```