



**Faculty of Electronic and Computer Engineering**

**DEVELOPMENT AND ANALYSIS OF NEAR-INFRARED  
SPECTROSCOPY TECHNIQUE FOR NON-INVASIVE BLOOD  
GLUCOSE MONITORING SYSTEM**

**Nurul Akmal binti Abd Salam**

**Master of Science in Electronic Engineering**

**2019**

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TECHNIQUE FOR NON-INVASIVE BLOOD GLUCOSE MONITORING  
SYSTEM**

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**A thesis submitted  
in fulfillment of the requirements for the degree of Master of Science  
in Electronic Engineering**

**Faculty of Electronic and Computer Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2019**

## DECLARATION

I declare that this thesis entitled “Development and Analysis of Near-Infrared Spectroscopy Technique for Non-invasive Blood Glucose Monitoring System” 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 the candidature of any other degree.

Signature :.....

Name : NURUL AKMAL BINTI ABD SALAM.....

Date :.....

## **APPROVAL**

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature : .....

Supervisor Name : DR. WIRA HIDAYAT BIN MOHD SAAD .....

Date : .....

## **DEDICATION**

For the sake of Allah, my Creator and my Master,  
My great messenger, Muhammad S.A.W who taught us the purposes of life,  
my beloved mother and father

## ABSTRACT

Blood glucose monitoring is necessary for diabetes management therapy, where the common method used is an invasive glucose meter that involves finger prick for blood sample which can cause discomfort and skin injury. Painless monitoring of blood glucose would improve patient's quality of life, therefore the development and analysis of near-infrared (NIR) spectroscopy technique for non-invasive blood glucose monitoring system was proposed in this research. An appropriate conditional circuit for photodiode was constructed and 3D sensor casing was designed for output signal stability and noise elimination. The NIR light-emitting diode (LED) with wavelengths of 1050 nm, 1200 nm, 1300 nm, 1450 nm, and 1550 nm and Indium Gallium Arsenide (InGaAs) photodiode were employed in the in-vitro analysis and the Dextrose solution with different concentrations was used as samples. Based on the analysis on the result of the in-vitro experiment, the NIR LED with the wavelength of 1450 nm had the best coefficient of correlation ( $R^2$ ) and it is used in the development of non-invasive blood monitoring device system. The in-vivo experiment utilises humans as subjects. The different area of the human body has a different absorption capability based on tissue composition and thickness. By considering that, three sensing areas, which are the finger, the area between the thumb and index finger, and earlobe, were selected for measurement. By referring to the measurement of the conventional invasive glucose meter, the earlobe area showed the best consistency of voltage output compared to other areas and this area was used to place the sensor prop for blood glucose measurement. A prototype of non-invasive blood glucose with the algorithm to convert voltage reading to glucose reading was developed based on the acquisition of the experiments that have been carried out. This prototype device has an LED indicator to alert the user about the condition of glucose level and Android application to monitor the blood glucose reading. In addition, this system of non-invasive blood glucose had also been developed with the temperature and motion parameters control for stability during the measurement. The Clarkson Error Grid (CEG) analysis was used to determine the accuracy of the measurement and the highest value of  $R^2$  indicates a good correlation between the measurement of the proposed device system and conventional invasive glucose meter. Based on the tests performed, the algorithms constructed based on a single subject demonstrate a high reading accuracy. The developed device system presented here has been proven to show a good correlation between NIR transmittance and blood glucose reading. However, as such an experimental device is not Food and Drug Administration (FDA) approved, it should only be used for academic or informative purposes, and should not be used for any medical decision-making process.

## ABSTRAK

Pemantauan glukosa darah adalah satu keperluan kepada terapi pengurusan diabetes, dimana kaedah lazim yang digunakan adalah meter glukosa invasif yang melibatkan tusukan jarum pada jari untuk mendapatkan sampel darah yang boleh menyebabkan ketidakselesaan dan kecederaan pada kulit. Pemantauan glukosa darah yang tidak menyakitkan akan meningkatkan kualiti hidup pesakit kencing manis dan oleh sebab itu, pembangunan dan analisis terhadap teknik spektroskopi inframerah dekat (NIR) untuk sistem pemantauan glukosa darah yang tidak invasif dicadangkan dalam kajian ini. Sebuah litar bersyarat yang sesuai untuk fotodiod dibina dan selongsong pengesan 3D direkabentuk untuk kestabilan isyarat keluaran dan penyingkiran bunyi hingar.. Diod pemancar cahaya (LED) NIR dengan jarak gelombang 1050 nm, 1200 nm, 1300 nm, 1450 nm, dan 1550 nm dan fotodiod Indium Galium Arsenide (InGaAs) digunakan dalam analisis in-vitro dan larutan Dextrose dengan kepekatan yang berbeza digunakan sebagai sampel. Berdasarkan analisis keputusan eksperimen, NIR LED dengan panjang gelombang 1450 nm mempunyai pekali korelasi ( $R^2$ ) terbaik dan ianya digunakan dalam pembangunan sistem peranti pengawasan darah yang tidak invasif. Subjek manusia digunakan dalam eksperimen in vivo sebagai sampel. Kawasan yang berbeza pada tubuh badan manusia mempunyai keupayaan penyerapan berbeza berdasarkan komposisi tisu dan ketebalan tisu. Setelah mengambil kira semua itu, tiga kawasan penderiaan, iaitu jari, kawasan antara jari ibu dan jari telunjuk, dan cuping telinga telah dipilih bagi pengukuran. Dengan merujuk kepada ukuran invasif meter glukosa konvensional, kawasan cuping telinga menunjukkan konsistensi terbaik voltan keluaran dan kawasan ini digunakan untuk meletakkan peralatan pengesan untuk pengukuran glukosa darah. Sebuah prototaip glukosa darah tidak invasif dengan algoritma untuk menukar bacaan voltan kepada bacaan glukosa dibangunkan berdasarkan hasil eksperimen yang telah dijalankan. Peranti prototaip ini mempunyai penunjuk LED untuk memberi amaran kepada pengguna mengenai keadaan aras glukosa dan aplikasi Android untuk memantau bacaan glukosa darah. Sebagai tambahan, sistem ini juga telah dibangunkan dengan kawalan suhu dan pergerakan parameter untuk kestabilan semasa ukuran. Analisis Grid Ralat Clarkson (CEG) digunakan untuk menentukan ketepatan pengukuran dan nilai  $R^2$  yang tertinggi menunjukkan korelasi yang baik antara pengukuran sistem peranti yang dicadangkan dan meter glukosa invasif konvensional. Berdasarkan kepada ujian yang telah dijalankan, algoritma yang dibina berdasarkan subjek tunggal menunjukkan ketepatan bacaan yang tinggi. Sistem peranti yang dibangunkan telah terbukti menunjukkan korelasi yang baik antara kehantaran NIR dan glukosa darah. Walau bagaimanapun, kerana peranti percubaan itu tidak diluluskan oleh Pentadbiran Makanan dan Ubat-Ubatan (FDA), ia hanya boleh digunakan untuk tujuan akademik atau dapatan data, dan tidak boleh digunakan untuk proses membuat keputusan dalam perubatan.

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## TABLE OF CONTENTS

	<b>PAGE</b>
<b>DECLARATION</b>	
<b>APPROVAL</b>	
<b>DEDICATION</b>	
<b>ABSTRACT</b>	<b>i</b>
<b>ABSTRAK</b>	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b>	<b>iii</b>
<b>TABLE OF CONTENTS</b>	<b>iv</b>
<b>LIST OF TABLES</b>	<b>vii</b>
<b>LIST OF FIGURES</b>	<b>ix</b>
<b>LIST OF APPENDICES</b>	<b>xv</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xvi</b>
<b>LIST OF PUBLICATIONS</b>	<b>xviii</b>
<b>CHAPTER</b>	
<b>1. INTRODUCTION</b>	<b>1</b>
1.1 Project background	1
1.2 Problem statement	4
1.3 Objective	5
1.4 Scope of project	6
1.5 Contribution of work	6
1.6 Thesis organization	7
<b>2. LITERATURE REVIEW</b>	<b>10</b>
2.1 Introduction	10
2.2 Blood glucose measurement methods	14
2.3 History of blood glucose monitoring systems development	15
2.3.1 First generation (invasive)	16
2.3.2 Second generation (invasive)	18
2.3.3 Third generation (minimally invasive)	20
2.3.4 Fourth generation (non-invasive)	22
2.4 Technologies of non-invasive blood glucose monitoring	26
2.4.1 Near-infrared spectroscopy	30
2.4.2 Mid-infrared spectroscopy	31
2.4.3 Thermal emission spectroscopy	32
2.4.4 Raman spectroscopy	33
2.4.5 Optical coherence tomography	33
2.4.6 Fluorescence	34
2.4.7 Occlusion spectroscopy	35
2.4.8 Polarimetry	36
2.4.9 Photoacoustic spectroscopy	36
2.4.10 Metabolic heat conformation	38
2.4.11 Bio-impedance spectroscopy	38
2.4.12 Reverse iontophoresis	39
2.5 Fundamentals of near-infrared absorption spectroscopy	41
2.5.1 Detector	41

	2.5.1.1	Modes of detector operation	43
	2.5.1.2	Dark current	45
	2.5.2	Main limitation and challenges	45
2.6		Experimental and analysis methods	46
	2.6.1	In-vitro sensing experiment of glucose	47
	2.6.2	In-vivo sensing experiment of glucose	47
	2.6.3	Analysis method	48
2.7		Relevant reviews of existing studies on NIR spectroscopy technique for non-invasive blood glucose measurement	49
2.8		Summary	54
<b>3.</b>		<b>RESEARCH METHODOLOGY</b>	<b>55</b>
	3.1	Introduction	55
	3.2	Block diagram of the project	56
	3.3	Hardware design and development	59
	3.3.1	Near-infrared and photodiode circuit design	61
	3.3.2	Thermistor sensor circuit	67
	3.3.3	Vibration sensor circuit	69
	3.3.4	Schematic combination circuit	71
	3.3.5	Sensor casing design	73
	3.4	Glucose sample preparation	74
	3.5	In-vitro glucose concentration measurement experiment	76
	3.6	In-vivo NIR non-invasive glucose measurement experiment	79
	3.6.1	Targeted areas for NIR non-invasive experiment	79
	3.6.2	Development of algorithms for NIR non-invasive glucose measurement	81
	3.6.2.1	Single subject algorithm development	82
	3.6.2.2	Multiple subjects algorithm development	83
	3.6.3	The invasive blood glucose measurement using glucose meter	83
	3.7	Prototype device testing and data verification	84
	3.8	Development of prototype non-invasive blood glucose measurement experiment	85
	3.9	Summary	91
<b>4.</b>		<b>RESULT AND DISCUSSION</b>	<b>92</b>
	4.1	Introduction	92
	4.2	In-vitro experiments	92
	4.2.1	Transmittance sensor configuration respond	94
	4.2.2	Reflectance sensor configuration respond	96
	4.3	Results and discussions of in-vivo NIR non-invasive glucose measurement experiment	100
	4.3.1	Targeted areas for NIR non-invasive experiment	102
	4.3.2	Algorithms development for non-invasive glucose detection	104
	4.4	Glucose prediction accuracy based on non-invasive prototype device (Non-invasive) and glucose meter (invasive)	108
	4.5	NIR non-invasive blood glucose monitoring prototype system	116

4.5.1	Temperature sensor calibration	118
4.5.2	Prototype device function	119
4.6	Summary	121
<b>5.</b>	<b>CONCLUSION AND FUTURE WORK</b>	<b>123</b>
5.1	Conclusion	123
5.2	Future work	125
	<b>REFERENCES</b>	<b>126</b>
	<b>APPENDICES</b>	<b>139</b>

## LIST OF TABLES

<b>TABLE</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Recommended target blood glucose level ranges for non-diabetes, pre-diabetes and diabetes (Holt et al., 2011)	12
2.2	Non-invasive glucose monitoring devices in the market (So et al., 2012)	23
2.3	Characteristics in different wavelength region (Frederick Chee and Tyrone Fernando, 2007) (Yadav et al., 2015)	31
2.4	Types of near-infrared light detector	42
2.5	The design review on the previous researcher	52
2.6	The previous studies that used combination other technique in the development	53
3.1	Near-infrared LED Thor Labs electrical specifications (Thorlabs, 2007)	63
3.2	Hamamatsu InGaAs photodiode specifications (Hamamatsu Photonics, 2015)	65
3.3	Types of amplifier used in the photodiode circuit	67
3.4	Thermistor specification and descriptions	69
3.5	The concentration of glucose solution samples	76
4.1	The output voltages of NIR transmittance configuration sensor based on different glucose concentrations	94

4.2	Line of linear regression equations and prediction correlation coefficient ( $R^2$ ) regressions based on graph Figure 4.2	96
4.3	The output voltage of NIR reflectance configuration sensor based on different glucose concentrations	97
4.4	Line of linear regression equations and prediction correlation coefficient ( $R^2$ ) regressions based on graph Figure 4.3	99
4.5	The measurements of glucose level before and after the meal based on three target areas	102
4.6	The measurements of prototype output voltage and invasive glucose meter based on samples from a single subject	104
4.7	The measurements of the proptotype output voltage and invasive glucose meter based on samples from multiple subjects	106
4.8	Summary of the experiments results for algorithms testing	115

## LIST OF FIGURES

<b>FIGURE</b>	<b>TITLE</b>	<b>PAGE</b>
1.1	The major complication of diabetes to the body	2
1.2	Block diagram of a simplified of light detector	3
2.1	The human system based on three conditions; (a) Normal condition (b) Type 1 diabetes (c) Type 2 diabetes	11
2.2	Trends and projections prevalence of diabetes in Malaysia by years 2020 (Ministry of Health Malaysia, 2011)	13
2.3	Overview of blood glucose measurement technologies (Ferrante do Amaral and Wolf, 2008)	14
2.4	Blood glucose monitoring approach using a FreeStyle glucose meter; (a) Finger pricking (b) Blood test by glucose meter (c) Self record	15
2.5	The revolution of the blood glucose monitoring device	16
2.6	The first portable blood glucose meter; Ames Reflectance Meter. This image from (David Mendosa, 2005)	17
2.7	The YSI 23A model of the glucose analyser. This image from (Newman and Turner, 2005)	18
2.8	Conventional devices of blood glucose meter with different size and design (ACCU-CHEK, FreeStyle, ONETHOUCH, Precision, MaxPlus, GlucoDr.)	19

2.9	Blood glucose meter test kit for blood glucose test; (a) Alcohol Pad (b) Needle Pen (c) Test Strip (d) Test Meter	20
2.10	The minimally invasive (CGM) device with insulin pump	20
2.11	Brands and models of CGM device available in market	21
2.12	GlucoTrack™ non-invasive glucose monitoring device	22
2.13	Overview on non-invasive glucose monitoring techniques	27
2.14	The diagram of different measurement configurations; a) Transmission b) Diffuse reflectance c) Transflectance d) Photoacoustic (Cunningham and Stenke, 2010)	28
2.15	The graph of the relation between Absorbance (A) and Transmittance (T) toward sample concentration	29
2.16	Basic system of optical non-invasive blood glucose monitoring	30
2.17	Schematic of OCT experiment set up by using arm	34
2.18	Fluorescence resonance energy transfer (FRET) fluorescence with ConA. (Oliver et al., 2009)	35
2.19	Basic setup of photoacoustic spectroscopy	37
2.20	Prototype using metabolic heat conformation blood sugar monitoring device from Hitachi	38
2.21	Schematic illustration of the principle of reverse iontophoresis showing an iontophoresis extraction device supplying a constant	40
2.22	GlucoWatch® biographer using reverse iontophoresis technique	40
2.23	A basic op amp trans-impedance amplifier	43
2.24	Connection of a photodiode to the trans-impedance amplifier in mode of photoconductive	44

2.25	Connection of a photodiode to the trans-impedance amplifier in mode of photovoltaic	44
2.26	Skin structure	48
2.27	Clarke Error Grid Analysis	49
2.28	Basic reflectance sensor arrangement (Yadav et al., 2014)	50
2.29	Ring-shape reflectance sensor arrangement	50
2.30	Basic transmittance sensor arrangement (Unnikrishna Menon et al., 2013)	51
2.31	Multi sensor transmittance sensor arrangement (Zeng et al., 2013)	51
3.1	Illustrates the block diagram of the flow in the methodology part. The block diagram shows from starting of the first step this project proposed to finish	57
3.2	The flowchart of circuit designing	60
3.3	The flowchart of custom 3D casing design	61
3.4	Block diagram of emitter and detector circuit	62
3.5	NIR conditional circuit	62
3.6	Near-infrared LED	62
3.7	Package of Indium Gallium Arsenide (InGaAs) photodiode	64
3.8	Photodiode circuit conditional (Hamamatsu Photonics, 2015)	65
3.9	The negative temperature coefficient (NTC) thermistor circuit	68
3.10	Vibration sensor circuit	69
3.11	HDX vibration sensor available position	70
3.12	The combination of the all circuits with Arduino processing board port; 1) Photodiode conditional circuit 2) LEDs indicator circuit 3) NIR LED	71



	circuit 4) Thermistor circuit 5) Vibration sensor circuit 6) Switch	
	7) Arduino ports	
3.13	Proteus PCB layout	72
3.14	The 3D view of circuit board in Proteus software	72
3.15	The casing design for in-vitro experiment used; (a) 3D view (b) Transmittance sensor configuration (c) Reflectance sensor configuration	73
3.16	The clipper casing design for in-vivo experiment used	74
3.17	Step of glucose concentration sample preparation	75
3.18	Flowchart of the in-vitro analysis	77
3.19	Cuvette fused quartz used for place the sample	78
3.20	Block diagram of transmittance configuration experiment	78
3.21	Block diagram of reflectance configuration experiment	78
3.22	Block diagram of in-vivo analysis	79
3.23	The targeted areas used in the experiment; (a) Earlobe (b) Finger (c) Between thumb and index finger	80
3.24	The flow chart of the in-vivo analysis using the prototype device	81
3.25	Invasive glucose meter equipment	83
3.26	Steps of blood glucose measurement using a glucose meter	84
3.27	The Bluno microcontroller board	86
3.28	Block diagram connection on microcontroller board	86
3.29	The flow chart of the microcontroller system (switching part)	88
3.30	The continuity of the microcontroller system flowchart (temperature and movement part)	89

3.31	The continuity of the microcontroller system flowchart (glucose and LED indicator)	90
4.1	In-vitro experiment; (a) In-vitro experiment setup (b) Transmittance sensor configuration (c) Reflectance sensor configuration	93
4.2	The relationship between voltage outputs of NIR transmittance configuration and glucose concentrations based on wavelengths; (a) 1050 nm (b) 1200 nm (c) 1300 nm (d) 1450 nm (e) 1550 nm	95
4.3	The relationship between voltage outputs of NIR reflectance configuration and glucose concentrations based on wavelengths; (a) 1050 nm (b) 1200 nm (c) 1300 nm (d) 1450 nm (e) 1550 nm	98
4.4	Experiment setup; a) In-vivo experiment setup (b) Clipper casing for sensor holder	100
4.5	The skin undertone spectrum (Sison, 2017)	101
4.6	The change pattern before and after the meal based on the targeted area	103
4.7	Line of linear regression graph of output glucose meter against output voltage non-invasive prototype device based on samples from single subject	105
4.8	Line of linear regression graph of output glucose meter against output voltage non-invasive prototype device based on samples from multiple subjects	107
4.9	The glucose measurement algorithm coded in Arduino microcontroller	109
4.10	Clarke Error Grid of single subject algorithm tested by same single subject	111
4.11	Clarke Error Grid of single subject algorithm tested by different single	111

	subject	
4.12	Clarke Error Grid of multiple subject algorithm tested by multiple subjects	112
4.13	Clarke Error Grid of multiple subject algorithm tested by single subject	113
4.14	Clarke Error Grid of multiple subject algorithm tested by using multiple subjects	114
4.15	The prototype of PCB board of the NIR non-invasive blood glucose monitoring	116
4.16	Bluno microcontroller processing board	117
4.17	The overall prototype system of NIR non-invasive blood glucose monitoring	117
4.18	The measurement test of skin temperature	119
4.19	The motion indicator LED	120
4.20	The normal blood glucose indicator LED	120
4.21	The hyperglycaemia blood glucose indicator LED	121
4.22	The hypoglycaemia blood glucose indicator LED	121

## LIST OF APPENDICES

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	The experiments data based on a single subject algorithm	139
B	The experiments data based on a single subject algorithm	144
C	Near-infrared LED Data Sheet	148
D	Indium Gallium Arsenide Photodiode Data Sheet	150
E	Bluno Microcontroller Board	154
F	Ethic of conduct form for human health related research	156
G	Research subject information and consent form	157

## LIST OF ABBREVIATIONS

CGMS	-	Continuous Glucose Monitoring System
NIR	-	Near-infrared
UI	-	User Interface
BLE	-	Bluetooth Low Energy
3D	-	Three-Dimensional
LED	-	Light-Emitting Diode
InGaAs	-	Indium Gallium Arsenide
WHO	-	World Health Organization
ISF	-	Interstitial Fluid
FDA	-	US Food and Drug Administration
CE Mark	-	European Commission
CO <sub>2</sub>	-	Carbon Dioxide
MIR	-	Mid-infrared
IR	-	Infrared
OCT	-	Optical Coherence Tomography
ConA	-	Concanavalin A
MHC	-	Metabolic Heat Conformation
Hb	-	Haemoglobin
SNR	-	Signal-to-Noise Ratio

Ge	-	Germanium
Si	-	Silicon
PbS	-	Lead Sulfide
Insb	-	Indium Antionide
PbSe	-	Lead Selenide
FGT	-	Fasting Glucose Test
OGTT	-	Oral Glucose Tolerance Test
RMSEP	-	Root-Mean Square Error of Prediction
R2	-	Prediction Correlation Coefficient
Ge	-	Germanium
Si	-	Silicon
PbS	-	Lead Sulfide
SEP	-	Standard Error of Predictions
EGA	-	Error Grid Analysis
PCB	-	Printed Circuit Board
PLA	-	Poly lactide
DC	-	Direct Current
PTC	-	Positive Temperature Coefficient
NTC	-	Negative Temperature Coefficient
UV	-	Ultraviolet
IDE	-	Integrated Development Environment
SMBG	-	Self-Monitoring Blood Glucose
ADC	-	Analogue to Digital Converter
IC	-	Integrated Circuit

## LIST OF PUBLICATIONS

The research papers produced and published during the course of this research are as follows:

1. Salam, N.A.B.A., bin Mohd Saad, W.H., and Salehuddin, F., Manap, Z.B., Karim, S.A. and Radzi, S.A., 2017. Comparative Study of Different Near-Infrared (NIR) Wavelengths on Glucose Concentration Detection. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)* 10(1), pp.2-6.
2. Saad, W.M., Salam, N.A., Salehuddin, F., Ali, M.A. and Karim, S.A., 2017. Study on Different Range of NIR Sensor Measurement for Different Concentration of Glucose Solution. *International Journal of Human and Technology Interaction (IJHaTI)*, 1(1), pp.13-18.
3. Salam, N.A.B.A., bin Mohd Saad, W.H., Manap, Z.B. and Salehuddin, F., 2016. The Evolution of Non-invasive Blood Glucose Monitoring System for Personal Application. *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, 8(1), pp.59-65.

Attended conference:

1. International Conference on Telecommunication, Electronic and Computer Engineering (ICTEC) 2017
2. International Conference on Telecommunication, Electronic and Computer Engineering (ICTEC) 2015

# CHAPTER 1

## INTRODUCTION

### 1.1 Project background

Diabetes is described as a syndrome of metabolism diseases due to abnormal blood glucose levels in the body. Among Malaysians nowadays, diabetes has become one of the most common diseases (World Health Organization (WHO), 2016). Diabetes is a lifelong illness as the patient is fully dependent on medicines that should be taken on the advice of the doctor to help supply or improve insulin function in the body itself. It can also cause many other diseases that can lead to several complications to the patients. Diabetes is a condition where there is an abnormal level of glucose in the human blood. In the human organism, glucose is the main carrier of the energy and the recommended glucose level varies from 4.9 mmol/L to 5.9 mmol/L within two to three hours after a meal for a healthy individual (Frederick Chee and Tyrone Fernando, 2007). Normally, blood glucose level increases slightly after the meal is taken and the abnormal increases of glucose level in the blood may be caused by the body that loses the ability to produce sufficient insulin or the failure of the body to respond properly to the insulin that has been produced by the pancreas.

In the long term, diabetes can affect other health complications to the patients. Diabetes-related complications include damage to large and small blood vessels, which can lead to heart attack and stroke, and problems with the kidneys, eyes, feet, nerves, and skin as illustrated in Figure 1.1. The risk of most diabetes-related complications can be reduced