A NON-INVASIVE ULTRA-WIDE BAND BASED SYSTEM USING ARTIFICIAL INTELLIGENCE TO DETERMINE BLOOD GLUCOSE LEVEL

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UNIVERSITI MALAYSIA PERLIS

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by

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LIST OF ABBREVIATIONS

AI	Artificial intelligence
ANN	Artificial neural network
BGCL	Blood glucose concentration level
BGMD	Blood glucose monitoring device
CE	European conformity
CFNN	Cascade forward neural network
CGMS	Continuous glucose monitoring system
DCT	Discrete cosine transform
DFT	Discrete fourier transform
DSC	Discrete sine transform
ECG	electrocardiogram
FCC	Federal communications commission
FDA	Food and drug administration
FFNN	Feed forward neural network
FFT	Fast fourier transform
GDM	Gradient descent with momentum
GHz	Giga hertz
GUI	Graphical user interface
Hb	Haemoglobin
IDF	International diabetes federation
IR	Infrared, Impulse radio
KSOM	Kohonen self-organizing map
LMS	Least mean square
MAE	Mean absolute error
MHz	Mega hertz
MIMO	Multiple input multiple output
MIR	Mid-infrared
MIST	Microwave imaging space-time
MLP	Multi-layer perception
MR	Magnetic resonance
MRI	Magnetic resonance imaging
MSE	Mean squared error
NGM	Non-invasive glucose monitoring
NIR	Near-infrared
NN	Neural network
OCT	Optical coherence tomography
PC	Principle component
PCA	Principal component analysis

PFA	Principal feature analysis
RBC	Red blood cell
RBF	Radial basis function
RCM	Ranging and communications module
RF	Radio frequency
RMSE	Root means square error
SNR	Signal to noise ration
trainlm	Levenberg-marquardt
trainrp	Resilient back propagation
trainscg	Scaled conjugate gradient
traingdm	Gradient descent with momentum
UWB	Ultra-wide band
VNA	Vector network analyser
WBC	White blood cell
WBAN	Wireless body area network
WHO	World health organization

Sistem Berasaskan Jalur Lebar Ultra Bukan Invasif Yang Menggunakan Kepintaran Buatan untuk Menentukan Tahap Glukosa Darah

ABSTRAK

Kencing manis merupakan satu kebimbangan yang serius terhadap kesihatan dan telah diisytiharkan sebagai wabak global oleh WHO kerana peningkatan kes-kes yang telah dilaporkan. Ia terbukti menjadi penyebab utama kematian di seluruh dunia. Bagi pesakit kencing manis, pemantauan tahap glukosa darah didalam julat fisiologi yang diizinkan adalah penting kearah kehidupan yang sihat. Oleh yang demikian, pemantauan secara kerap membantu penyembuhan penyakit ini terutama bagi pesakit kencing manis tahap-1. Kaedah pemantauan kebiasaanya dilakukan melalui kaedah pengujian makmal atau pengujian diri yang menggunakan peranti kecil untuk menganalisis sampel darah yang diambil dari bahagian tubuh dengan menggunakan jarum suntikan. Bagi kaedah yang mencabar ini, pesakit kencing manis adakala perlu menjalani proses yang menyakitkan ini berkali-kali dalam sehari. Oleh itu, bagi mengurangkan penderitaan ini, satu kaedah bukan invasif (tanpa apa-apa sampel darah) dan cara yang lebih mesra adalah amat penting untuk membantu pesakit. Oleh yang demikian, ciri unik serta berfaedah yang ada pada teknologi UWB telah digunakan secara meluas dalam aplikasi bio-perubatan, diantaranya untuk pengesanan awal kanser payudara. Dalam penerokaan potensi bukan invasive bagi tujuan penyembuhan dan pengesanan penyakit kencing manis, UWB adalah salah satu alternatif berasaskan kepintaran buatan yang boleh digunakan. Ianya bergantung kepada perubahan sifat dielektrik (ketelusan dan kekonduksian) tisu atau sel-sel sasaran berdasarkan frekuensi yang telah dihantar. Pada permulaannya, eksperimen ini menyediakan pelbagai jenis antena buatan sendiri bagi tujuan pemilihan antena yang sesuai, tempat pengukuran badan yang sempurna, supaya dapat mengesahkan kebuktian konsep ini. Dalam suatu sistem bersepadu, antena segi empat tepat telah ditetapkan dengan transceiver untuk menjana frekuensi 4.3 GHz supaya dapat melalui cuping telinga. Isyarat diskriminasi bertaburan yang diterima lalu diproses dan nilai-nilai diskret telah dikurangkan untuk digunakan sebagai nilai kemasukan ke rangkaian neural kecerdasan buatan (ANN). Beberapa ujikaji telah dijalankan untuk membangunkan suatu modul ANN yang optimum di mana glukosa darah sebenar telah digunakan sebagai sasaran. Rangkaian keluaran akhir telah digunakan untuk mendapatkan bacaan glukosa darah dari nilai isyarat bertaburan yang telah diterima. Sistem perbandingan keluaran dan bacaan sebenar menunjukkan ketepatan system ini. Kajian ini merupakan usaha awal dengan hasil keluaran yang konsisten serta memiliki purata ketepatan kira-kira 84%, ianya jelas menunjukkan kebolehpercayaan dan kejayaan awal sistem ini. Perbandingan diantara keputusan keluaran dengan teknologi yang sedia ada, sistem ini adalah lebih mudah untuk beroperasi dan dengan kos yang sangat efektif tanpa sebarang prasyarat penentukuran. Oleh itu, sistem ini dapat membantu menyediakan sokongan mesra pengguna pada harga yang berpatutan, serta selamat kepada pesakit kencing manis. Permulaan sistem baru ini bukan sahaja akan meningkatkan kemudahan pemantauan, pada masa yang sama ianya akan mengurangkan keperluan rawatan, serta dapat membantu penjimatan kos operasi kepada pusat-pusat rawatan.

A Non-Invasive Ultra-Wide Band Based System Using Artificial Intelligence to Determine Blood Glucose Level

ABSTRACT

Diabetes is a serious health concern and declared as global epidemic by WHO due to its rapidly increasing incidence. It is a major cause of mortality worldwide. For a diabetic patient maintenance of blood glucose level within the physiological range is essential to lead a healthy life. The frequent monitoring of blood glucose is an important part of diabetic management specially for type-1 diabetes. A laboratory test or self-test with a small device uses a blood sample collected from a body part with a needle. In extreme cases a diabetic patient needs to undergo this painful process several times a day. To reduce this suffering, a non-invasive (without any blood sample) and patient friendly way of measurement is crucial. Unique advantageous features of UWB technology has demonstrated the widely use of biomedical applications, specially for early breast cancer detection. In the field of exploring potential non-invasive solutions to diabetes detection one promising alternative can be UWB based system using artificial intelligence technique. This relies on variation of dielectric properties (permittivity and conductivity) of target tissues or cells in a given frequency. Initially the experimental setup was prepared with different types of homemade antennas to select the appropriate antenna type, perfect measurable body place, and to confirm the proof of concept. In integrated system a rectangular patch antenna was fixed with a transceiver to generate 4.3 GHz frequency and pass through the earlobe. Received discriminated scattered signal was processed and discrete values were reduced to use as input of artificial neural network (ANN). Number of experiment was conducted to construct an optimal ANN module where actual blood glucose was used as target. The final network output was used to obtain the blood glucose reading from a given scattered signal value. The comparison system output and actual reading showed the accuracy of system. The study was a preliminary effort with a consistent result with an average accuracy of around 84%, showing the initial system success with reliability. Compare the result with the existing technologies, this system is simple to operate and cost effective without any calibration prerequisite. Hence, the system provides affordable, safe and user friendly support to the diabetes patients. Inception of this new system will not only increase the measurement facilities, but also significantly ease up the requirements on treatment, and cost saving to the health care system.

CHAPTER 1

INTRODUCTION

1.1 Overview

Diabetes is a chronic, metabolic disease characterized by high levels of blood glucose (often named as blood sugar), which leads over a prolonged period of time to serious damage to the heart, blood vessels, eyes, kidneys, nerves and so on. The disease causes the symptoms of frequent urination, hunger, increased thirst, hyperosmolar coma and diabetic ketoacidosis (Tao, Shi, & Zhao, 2015). Diabetes takes place due to insufficient insulin production by the pancreas or the cells of the body do not respond to the produced insulin properly. There are three types of diabetes (Canivell & Gomis, 2014):

Type-1 diabetes consequences from the body which produces no or not sufficient insulin (Foster, Miller, Tamborlane, Bergenstal, & Beck, 2016). This is recognized as insulin-dependent diabetes or juvenile diabetes. Still, the origin of this type is unidentified.

Type-2 diabetes begins with insulin resistance (Felton *et al*., 2016), in which body cells do not respond to insulin properly. Lack of insulin also observed during the progress of this type. This type is recognized as non-insulin dependent diabetes or adult-onset diabetes. Besides hereditary, the basic cause of this type is imbalance food habit, less physical activity, and excessive body weight.

Gestational diabetes (Harrison, Shields, Taylor, & Frawley, 2016), women without a previous history of diabetes develops high blood sugar, develops during pregnancy and usually disappears after giving birth. This type is short-term and treatable.

The prevention and treatment of diabetes involve a smoke-free healthy diet with normal body weight and regular physical exercise (Tao *et al*., 2015). Controlling Blood pressure and less intake of sugar is also very important for a diabetes patient. There is no option rather use an injection of insulin to manage Type-1 diabetes. Oral medications can be used for Type-2 but some cases it also is needed to use an injection of insulin to treat that. Gestational diabetes usually resolves after the birth of the baby.

Rapidly increasing status is aided to declare the diabetes as a serious health concern and global epidemic by world health organization (WHO) in 2016. According to International diabetes Federation, half a million children with age 14 years and below living with Type-1 diabetes and there are 415 million adults between the age of 20 - 79 years with Type-2 diabetes worldwide. This resulted in around 5 million deaths with a healthcare cost of around $673 to $1,197 billion in the year 2015. If the trend continues, by 2040 there will be around 642 million diabetes patients (International Diabetes Federation, 2015). Therefore, diabetes is increasing at an unprecedented pace and causing a potentially serious epidemic worldwide. It is a prime cause of mortality in the age group of 20 - 79 years (Vashist, 2013). Maintenance of blood glucose level within the physiological range enables a diabetic to lead a healthy lifestyle by avoiding diabetic complications such as diabetic retinopathy, kidney damage, heart diseases, stroke, neuropathy and birth defects (Tao *et al*., 2015). Frequent monitoring of blood glucose is an essential part of diabetic management which is done in laboratory or self-test at home using a small device (Newman & Turner, 2005). The commercial market of blood glucose meters is very substantial, worth around 11 billion USD, which accounts for 85% of the total biosensors market of the world and dominated by Roche, Bayer, Abbott, Medtronic, LifeScan and Nova biomedical (Medical device market, 2016).

Most of the commercial blood glucose monitoring devices (BGMD) are invasive, employ an economical electrochemical biosensor, which is capable of responding rapidly to glucose detection (Newman & Turner, 2005). Those use lancet devices to punch the fingertip to collect a blood drop, which is painful and cause a traumatic effect when a patient needs to follow the process for several times a day (Vashist, 2012). There have been tremendous efforts to develop improved BGMD with reduced blood sample requirement of less than 1 micro (μ) liter in the last few decades. The painful part is also mitigated by using alternate sampling sites like- hand, arm or foot and use of 32 gauge lancet (Vashist, 2013). However, besides distress, the cost of the strip and the discomfort of making recurrent measurements are becoming a vital issue. The minimally invasive approaches have been introduced by using subcutaneous sensors to determine glucose level in interstitial fluid which usages a tiny electrode beneath the skin, also suffer from limitations in terms of discomfort to patients, requirement of continuous calibration, fixed limited lifetime of electrode, and high vulnerability to befouling (Vashist, 2012). Therefore, the development of non-invasive glucose monitoring (NGM) device is the only way to overcome those limitations and provides improved pain-free glucose monitoring environment for a diabetic patient. This is the major stimulant for continuous ongoing developments in the field of NGM technology. Progressive research efforts observed in the last few decades as presented by the rapidly cumulative number of publications in NGM field in Fig. 1.1.

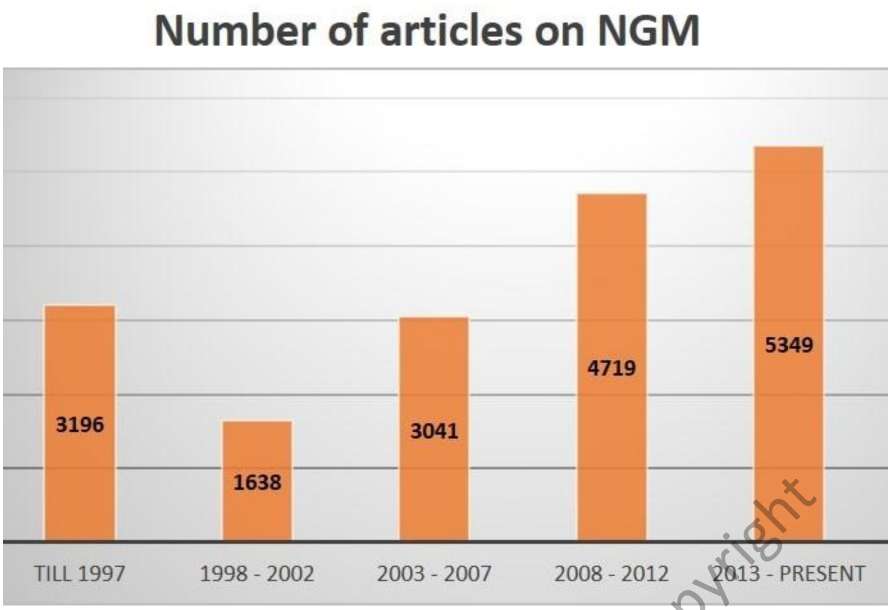

Figure 1.1: NGM article publication during the mentioned period (data considered on 22 November 2016 using "Glucose monitoring" and "Non-invasive" in the advanced search option of www.sciencedirect.com).

From these statistics, it is clear that it is of immediate and indisputable importance to find new methods or techniques for blood glucose detection in order to provide continuous pain-free test and ensure treatment to patients as early as possible.

S. K. Vashist (2012) and Chi-Fuk So *et al* (2012) comprehensively analyzed a number of potential NGM devices and techniques along with their benefits, shortcomings, challenges and future potentiality. Besides, to monitor Hemoglobin (Hb) (Kim *et al.*, 2014), Oxygen saturation (Hiscock, Simmons, Carstensen, & Gurrin, 2014), and Pulse rate (Bilich & Chlamtac, 2006) some non-invasive technologies were also invented. Despite of huge effort, due to inconsistent accuracy, those couldn't survive and fade away from the market. Presently GlucoTrack (I. *et al.*, 2009) in the field of glucose monitoring and NBM-200 (Kim *et al.*, 2014), Radical-7 (Skelton *et al.*, 2013) and Promto-7 (Hiscock *et al.*, 2014) respectively in the field of Hb, oxygen saturation and pulse rate monitoring are successful and existing in the market now. However, those systems are expensive and need frequent calibration and yet to prove the worthiness. Microwave radar-based has demonstrated a promising technology in the field of biomedical which transmits and receives a short ultra-wideband (UWB) pulse (Bilich & Chlamtac, 2006).

UWB is a type of technology, uses radio energy to transmit the information. Beneficial features like- low power, high bandwidth, not hazardous to health have made UWB technology very popular among the researchers and used widely in biomedical applications. The bandwidth of UWB is 3.1-10.6 GHz according to federal communications commission (FCC) (Zhi, 2007). In the field of exploring potential non-invasive solutions for blood pathology, one alternative can be artificial neural network (ANN) technique (Amato *et al*., 2013). UWB signal pulse can be incorporated into the system, which was potentially used for early cancer detection, which relies on changes in dielectric properties (permittivity and conductivity) of target tissues or cells. UWB technology has a significant advantage due to its easy penetration and non-ionizing nature. E. Topsakal *et al* (2011) observed that dielectric constant and conductivity decrease when glucose concentration is increased in blood plasma. The performance of UWB system relies on the change of blood dielectric properties as a function of frequency. Conceptualizing this concept, this research pursue to develop a UWB imaging based system using AI for detecting reliable blood glucose concentration level (BGCL).

1.2 Motivation and Problem Statement

Blood test is a common and regular phenomenon for a diabetes patient which to be performed in laboratory or self-test through a commercial device. For all cases a blood sample to be collected from the body using a needle which is painful (So *et al*., 2012). In extreme cases, a diabetic patient may need to undergo this process several times a day. To overcome this problem, a non-invasive and patient-friendly way of measurement is essential.

To overcome this shortcoming a good number of researches have been conducted in the non-invasive field and aided to emerge with new devices with various technologies. The devices were expensive and displayed inconsistent results (Vashist, 2012). To discuss on specific technology bio-impedance spectroscopy requires an equilibration process, where the user has to in rest position for 60 minutes before starting the measurement. More so it is affected by temperature and body water content while taking a reading. Temperature has a strong effect on electromagnetic sensing (Ferrante do Amaral & Wolf, 2008). Fluorescence technology suffers from strong scattering phenomena. Mid-infrared spectroscopy has got poor penetration capacity. Individual's motion effects on optical coherence tomography. Raman spectroscopy has got a limitation on the instability of laser wavelength. Electrodes placed on skin creates huge irritation in case of reverse iontophoresis. Ultrasound technology is sensitive to interference from some biological compounds, temperature fluctuations, and pressure changes (So *et al.*, 2012). Despite advantages, all the technologies suffer from major limitations which hinder to invent a flawless non-invasive device. Improvement of signal to noise ratio (SNR) and sensitivity while measuring data are the key challenges for the development of non-invasive devices (Vashist, 2012)

Microwave based technology has proved some significant development in the field of non-invasive technology. Alshehri & Khatun (2011) assured about the existence, size, and location of a breast tumor with almost 100% detection rate by their experimental work with UWB imaging and Neural Network. Reza (2014) in his work, early detection of a breast tumor using UWB system, could successfully conclude and guided for future research on human body tissue to apply and validate the actual performance using his designed system. So, all these perceptions have got strong potentiality to use in the field of non-invasive technology. Inspiring of this the effort is being taken to pursue on artificial intelligence (AI) based UWB system technique.

Laboratory blood test is reliable but require large quantity of blood sample and cannot perform frequently. Invasive technique needs to punch body tissue to extract a drop of blood, but over time this measurement gives pain and traumatic effects to the patient. Minimally invasive technique practices an electrode beneath the skin to obtain a continuous measurement. This is painful and causes irritation to skin, electrode needs to be changed after a certain time and it's expensive too. Non-invasive technology replaces the blood sample with other body fluid like- saliva, tear, urine, and so on. A good number of devices with various technologies were introduced but soon withdrawn from market due to inconsistency, inaccuracy, and discomfort. Most of those technologies were badly foiled by temperature fluctuation, water contamination, sweat, movement, pressure changes. So, there is a potential demand of accurate, consistent, user-friendly, low-cost non-invasive device. UWB spectrums are non-ionizing electromagnetic waves, operate below the noise level. Thus, harmless to human body. UWB imaging technique with the artificial neural network has proved a successful result in early breast cancer detection. The method can be modified and adapted for detection of blood glucose concentration level.

To the best of author's knowledge, so far no research has been reported for UWB imaging or system to detect blood glucose concentration level using AI non-invasively. Hence, this research targets to investigate the feasibility of AI based UWB system to detect blood glucose and develop an affordable and user-friendly system for blood glucose investigation. To do so it requires adapting an intelligent Neural Network (NN) module and suitable antennas for experimental investigation.

1.3 Aim and Objectives

The aim of this research is to develop an Ultra-wide Band (UWB) and Artificial Intelligence (AI) based system application to determine blood glucose concentration level non-invasively. To achieve this aim following objectives are set:

1. To investigate on UWB antennas and body parts, which can be best suited for reliable blood glucose detection.
2. To develop a system model using optimized neural network for auto-analysis of UWB pulse to obtain blood glucose level.
3. To integrate the hardware as UWB antenna and software as optimized neural network to compare the actual blood glucose level.

1.4 Research Scope

This research was directed to design and construct a system to detect blood glucose level non-invasively. To achieve that, available antennas in lab were investigated to select a suitable one. Left hand muscle and earlobe were compared to choose the appropriate body part for the purpose of collecting signal data. Central frequency of 4.3 GHz was generated using commercial transceiver to obtain discriminated receive signal pulse. Actual blood glucose values were collected using commercial glucometer from self-motivated students and local volunteers having written consent.

Artificial neural network (ANN) module was constructed after computing number of tests. Discrete signal data values were reduced and used as ANN input whereas actual blood glucose values were used as target of ANN. Analysis was done to specify the number of nodes to be fixed in hidden layer. Optimization of training function was also carried out. The net was trained, tested, and validated to find the exact type to construct the ANN module. It is worth to mention that ANN module and system automation were conducted in Matlab based environment. Finally, with the integration of hardware and software, a non-invasive system was developed which can monitor or identify blood glucose level clinically or domestically.

1.5 Expected Outcome

Invasion of a complete non-invasive device based on UWB system. Initially, the conceptual prototype to be confirmed which lead the further exploration. Final experimental result assist to develop the device. Final product would be an unique non-invasive device which is affordable, durable and user friendly.

1.6 Organization of the Thesis

This thesis includes total five (5) chapters. Chapter 2 comprises of the literature review where previous research and related issues of this subject are discussed in details in a segmented way. Chapter 3 contains the methodology with experimental system design scenario. Chapter 4 contains the experiment results, discussion, and their comparison analysis and finally, Chapter 5 concludes the research with limitations and a guide to possible future directions.