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Proposed Application of Fast Fourier Transform in Near Infra Red Based Non Invasive Blood Glucose Monitoring System

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Abstract. Worldwide emergence of glycaemic status related health disorders, such as diabetes and metabolic syndrome, is growing in alarming rate. The objective was to propose new methods for non invasive blood glucose level measurement system, based on implementation of Fast Fourier Transform methods. This was an initial-lab-scale-research. Data on non invasive blood glucose measurement are referred from Scopus, Medline, and Google Scholar, from 2011 until 2016, and was used as design references, combined with in house verification. System was developed in modular fashion, based on aforementioned compiled references. Several preliminary tests to understand relationship between LED and photo-diode responses have been done. Several references were used as non invasive blood glucose measurement tools design basis. Solution is developed in modular fashion. we have proven different sensor responses to water and glucose. Human test for non invasive blood glucose level measurement system is needed.

Keywords : fast Fourier transform, non invasive blood glucose monitoring system, proof of concept

1. Introduction

Worldwide emergence of glycaemic status related health disorders, such as diabetes and metabolic syndrome, is growing in alarming rate [1]. Worldwide current prevalence of aforementioned disorders is between 6.6 % [2] to as much as 30 % [3,4]. Indonesia reported 2.1 % prevalence of diabetes [5], but the real number possibly 5 times larger [1] due to different methods in diagnosing diabetes.

Blood glucose level measurement is integral part on glycaemic status management [6,7]. Current available methods include invasive and cause discomfort [8], need laboratory test [9], and expensive use of 1 time use biosensor [10,11]. Research for non invasive methods on blood glucose level measurement have been conducted [12,13], but the results were not yet satisfactory.



This research objective was to propose new methods for non invasive blood glucose level measurement system, based on implementation of Fast Fourier Transform methods, and to develop proof of concept to the solution.

2. Method

Data on non invasive blood glucose measurement are referred from Scopus, Medline, and Google Scholar, from 2011 until 2016, indexed using Docear [14] and Zotero [15] and was used as design references, combined with in house verification. System was developed in modular fashion, based on aforementioned compiled references. Several preliminary tests to understand relationship between LED and photo-diode responses has been done. All calculation needed done with Libre Office Calc [16] and R [17].

3. Result

3.1. Several references is used as non invasive blood glucose measurement tools design basis

The solution structure largely inspired by works of Farshad and Szabo [18,19]. The aforementioned tools are amperometric [20], micro controller based [21,22], and using piezo electric sensor [23]. They were both portable [24] and wearable [25]. It implemented machine learning algorithm [26,27]. Sensor works based on modulated spectrophotometry [28,29] in the Near Infra Red (NIR) range [30]. Tools were able to monitor blood glucose continuously [31,32].

NIR Light Emitting Diode (LED) and Photo-diode in 1000 nm – 1700 nm wavelength range are used, provided by Thorlabs [33,34]. Wavelength selected based on works by Smith and Goodarzi [35,36], which was confirmed by our own unpublished research. NIR LED and Photo-diode mounted on 3 dimensionally printed [37,38] probe, modulated by Raspberry Pi [39] through Inter-Integrated Circuit (I²C) protocol [40]. Spectrum data are transformed using Fast Fourier Transform (FFT) [41] and will be inferenced using Cascade Correlation Artificial Neural Network [42]. Results are stored in SQLite database [43]. Whole system developed with Qt Software Development Kit (SDK) [44,45].

3.2. Solution is developed in modular fashion

System was developed in 5 independent modules (Figure 1). Sensor module / probe was printed from poly-lactic acid (PLA) [46,47], housing a pair of 1 or 2 NIR LED and a photo-diode. The LED is modulated in serial, in a period of certain seconds. The resultant spectrum data are pushed to repository module.

Analogue to Digital Converter (ADC) module implemented MCP 3424 [48] was used to enable 14 bit conversion at 60 measurement / s data rate. LED modulated using pulse width modulation (PWM) [49], and controlled with different intensity between each measurement period. It was attached to CPU module by data wire.

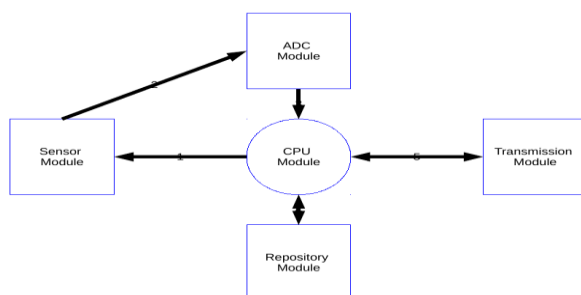


Figure 1. Non Invasive Blood Glucose Measurement System modular structure.

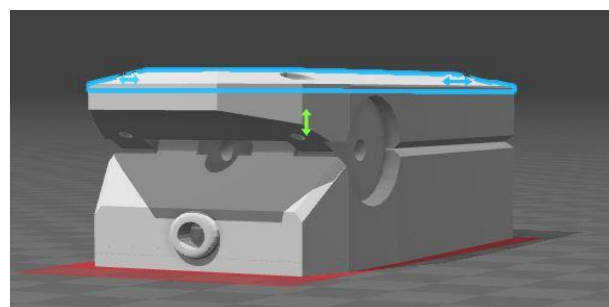


Figure 2. Non Invasive Blood Glucose Measurement probe.

Repository module was made in 2 parts. 1st part was implemented in each devices, as SQLite [43] database, which reside within SD Card. It stored both measurements spectrum and result of measurements, including measurement context such as user, measurement site, location, time, and device used.

Central Processing Unit (CPU) module houses the application built with Qt SDK [44,45]. The application sample the measurement in several seconds periods, and process the output of ADC Module using open source FFTW [41] class. The output would be fed to inferencing module implementing cascade correlation artificial neural network (CCANN) [42], to transform FFTW output into blood glucose level measurement values.

Transmission modules is a conglomerate of modules essential for serving human blood glucose measurement values, whether for monitor display for user view, or to be wireless transmitted over networking modules such as wireless Fidelity (Wi-Fi) or Blue-tooth modules.

Sensor and ADC module are housed together in probe module (Figure 2), and reminder modules are housed together in main module (Figure).

3.3. In preliminary test, we have proven different sensor responses to water and glucose.

We have done our preliminary testing against pure glucose and pure water (Figure 3). We have proven that the photo-diode gave different reading when given different LED intensity (Figure 4). Furthermore, the photo-diode gave different responses to different substances.

Research to find relationship between glucose meter reading, glucose water concentration, and photo-diode responses are still on going.

4. Discussion

4.1. This is the first research that propose Fast Fourier Transform as data transformation methods to measure blood glucose level

To our knowledge, this is the 1st time for Fast Fourier Transform based methods that is used for blood glucose level measurement spectrum transformation. The research combines strength of previous researches, mainly on the usage of modular spectrophotometry.

This research also confirm possibilities in non invasive blood glucose monitoring system, including wavelength used and one possible probe and case shape. We also proved that the system can be developed modularly, enabling different rate of development and reusing same core system to do different biomarker measurement.

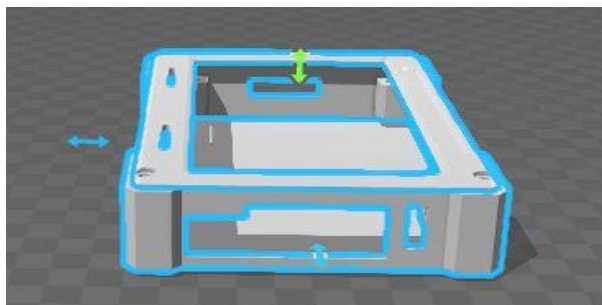


Figure 3. Non Invasive Blood Glucose Measurement outer case.

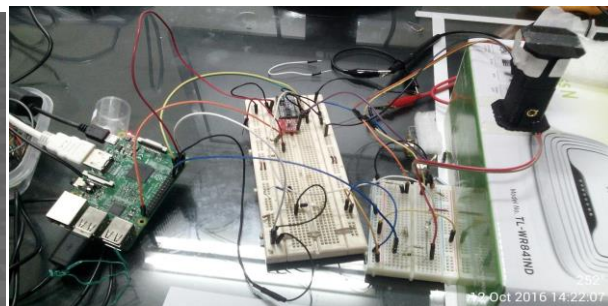


Figure 4. Non Invasive Blood Glucose Measurement Tools trial. Cases and Probe not shown. LED and photo-diode attached to dark tube for simulated response testing, which filled with substance cuvette.

4.2. While several methods exist, none of non invasive blood glucose level measurement methods are proven

Non invasive blood glucose measurement is a relatively new fields. Until the time when this manuscript written, only 13 trials indexed at ClinicalTrial.gov [50] running, most notable, trial by Lamberg and Nimri [51,52], and none of them have published their results. Furthermore, none of aforementioned non invasive glucose methods have been clinically trialed.

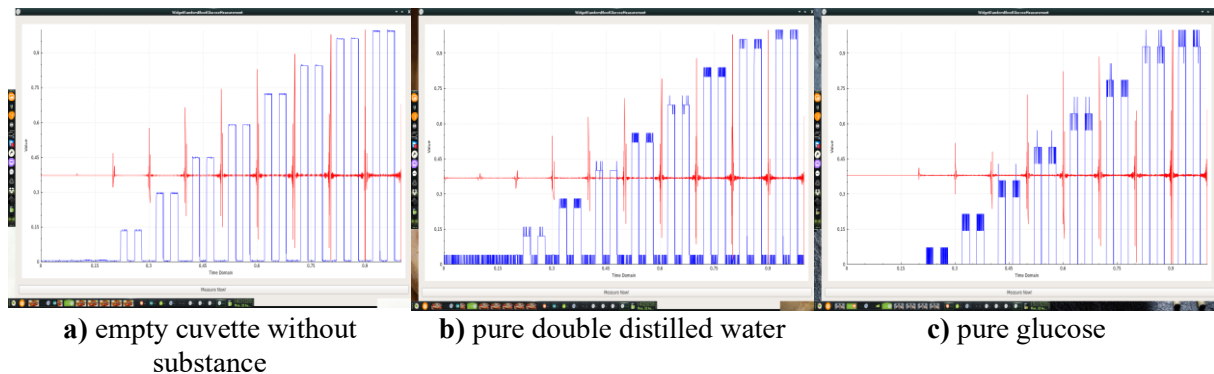


Figure 5. Different responses from photo-diode to different substances. In the photograph is the actual application view for testing. All chart is mapped to [0, 1] values. Real photo-diode reading in blue bar shaped lines, and Fast Fourier Transformed values in red fish bone shaped lines.

Even then, our internal testing show some promises. We have proven different photo-diode responses to pure water and pure glucose, which open possibilities of non invasive blood glucose measurement.

4.3. Best wavelength, measurement site, and probe shape still being researched

There has been a dispute for proper wavelength to detect and measure blood glucose level. Several values exist, from as low as 800 nm [35], to as high as 2500 nm [53]. We have confirmed several wavelength in our unpublished research, but only to glucose and water solution. Ethical clearance pending, so we not yet able to conduct human test for the solution. Furthermore, LED and Photo-diode upward of 1700 nm is too expensive at the time of this writing, rendering procurement and testing of those wavelength not yet possible.

While several body nodes have been used for non invasive blood glucose measurement in previous researches, commonly in fingers, none actually comparing between several possible nodes, like each finger or each ear. We cannot use nodes for finger prick based glucose meter sites as reference, because we did not face similar risks. This imply that we have yet to test optimal shape of measurement probe.

4.4. The proposed solution is a compromise between component capabilities

There are 5001 different integer values between 0.0 mg / dl to 500.0 mg /dl, assuming 1 value after decimal, which is the extreme range of human blood glucose level. That make usage of 13 bit [0 to 8191] ADC necessary. MCP 3424 [48] able to generate 14 bit data [0 to 16383] at 60 datum/s, but that too slow to flood simple serial port, making usage of Arduino [54,55] as intermediary is impossible, hence why direct I²C control is used instead.

Another problem, Raspberry Pi [39] only have a pair of functional I²C pins, hence made usage of Digital to Analogue Converter (DAC) module in tandem with ADC module impossible; they shall interference with each other. That means, the I²C can only used for ADC, and the LED is controlled using PWM.

4.5. This proposed system can change the way glycaemic status treatment is conducted, but human tests is needed for confirmation.

Traditional glucose meter finger prick based blood glucose measurement can only measure as fast as 4 measurement/hour, mainly due to risk of inflammation and discomfort of patient. This system by concept can measure up to 60 measurements / hour, and wearable, enabling continuous telemetry.

We have yet to test whether different body composition on different body site, muscle, water, skeleton, blood composition, and others, and different medical condition, like hypo hydration, can change blood glucose level reading. Furthermore, We have yet to find proper measurement calibration for human blood glucose level in different body sites.

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RPJ, HA, I, ED, and R, design the whole study. RPJ design and implemented the software and analytical methods and running the whole research. RPJ, HS, HA, and R design the data transformation and inference module. JI, AK, ER, and I design the probe and electronics parts. RPJ and NMN handling system testing. TH, JP, RF, and YS handling electronics printing. MSKR provide information regarding proper medical testing equipment. DS observe the study. This manuscript prepared by RPJ and HA.

We declare non competing interests.

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