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Smartphone-based laser glucometer for non-invasive measurement of glucose level of diabetic patients

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Abstract

A glucose meter (or glucometer) is a medical device for determining the approximate concentration of glucose in the blood by pricking a finger to draw blood sample using a sharp needle. However, diabetic patient has quite slow level in wound healing process which causes their fingers constantly in a state of wounded and exposed to bacteria. More importantly, two main factors for the weakness of invasive technique is a painful process and cost often because constant monitoring of glucose level is very expensive. The main objective of this research is to design and develop a non-invasive optical measuring technique to measure body glucose level automatically and painlessly using a laser pointer and a smartphone. Images captured by the smartphone is analysed using a Matlab software to determine the refractive index of the urine sample. Calibration of the system is performed by correlating the results with that of the glucometer. Both results compare well with R-squared value of 92.9%. The system can be potentially used for remote health and patient monitoring.

Keywords: diabetes; glucose; monitoring; measurement; non-invasive

1. Introduction

Diabetes Mellitus is a serious ailment in which the body does not generate or appropriately utilize insulin. World Health Organization (WHO) stated that about 3.4 million people died due to high blood glucose in 2004, and 347 million people worldwide have diabetes. High glucose in blood may lead to heart disease, damage in nerves and veins, blindness, limb amputations, kidney disease and cardiovascular disease. In addition, it may causes complications during pregnancy, rapid aging and weight loss. The main cause of diabetes is still scientifically unclear but scientists consider body weight, diet, gender, genetic and living style as the major contributors for most cases (Williamson, 2009).

There are two principal types of diabetes which are Diabetes Type 1 and Type 2. Diabetes Type 1 frequently happens in children and young adults, in spite of the fact that it can happen at any age. This is caused due to an autoimmune insulin-producing β-cells in the pancreas have been destroyed by interstitial cells that lead to the real causes of the lack of insulin. Lack of insulin thwarting the normal regulation of blood glucose. In some cases, Type 1 often genetically inherited diabetes. Typically, bacteria, virus, and other harmful foreign materials are damaged by the immune system to protect the body. But, the immune system cracks down on body's own cells in autoimmune diseases (Khalil, 1999). In Type 1 Diabetes, decay of β-cell can take several years, but symptoms of this disease usually occur in a short period of time (Williamson, 2009).

In addition, Type 2 diabetes results from insulin resistance triggers the symptoms. Literally, people who have a healthy lifestyle such as physical activity are high, vibrant lifestyle, and do not have the habit of smoking is less prone to problems related to diabetes. Diabetes Type 2 is often faced by patients due to several factors, including insulin resistance that a state in which the body's muscles, fat, and liver cells cannot use insulin effectively (Srivastava, Chowdhury, Sharma, & Sharma, 2013). By the way, the ability of reduced visibility because the body can no longer produce enough insulin to compensate for vision capabilities. Symptoms of Type 2 Diabetes affect the body precisely and grow gradually and sometimes take the next several years to diagnose. The disease develops most often in the middle-aged and older people who are overweight or obese (Williamson, 2009). Type 2 Diabetes is rare among the youth, however, is common in children who are overweight and obese children and adolescents with diabetes.

In general, blood glucose can be measured using three techniques which are invasive, minimally invasive, and non-invasive. Technically, invasive techniques are mostly used for the measurement of glucose known as glucometer devices. A glucose meter (or glucometer) is a medical device for determining the approximate concentration of glucose in the blood by pricking a finger to draw blood as the sample using a sharp needle. Glucometer will use a strip of paper and

dipped into blood samples to measure blood glucose levels and it is widely used because it has a relatively high accuracy (Shichiri, Yamasaki, Kawamori, Hakui, & Abe, 1982).

However, diabetes patient has quite slow level in wound healing process which causes their fingers constantly in a state of wounded and vulnerable to germs and bacteria. Even patients with diabetes Type 1 and Type 2, they need to constantly monitor their own blood glucose levels several times a day as to keep the blood glucose level at normal or near-normal range (Williamson, 2009). Usually if the level of blood glucose is low at less than 4 mmol/l it is known as hypoglycaemia. Diabetes patients will face a several number of symptoms such as shaking, sweating a lot, blurred vision, headache, too tired and lack concentration. While the hyperglycaemia also mean glucose is in the high level of which more than 7 mmol/l. Diabetes patients will often want to urine, too thirsty and headache when in a state of hyperglycaemia.

Despite that, this method is painful, expensive, cumbersome, aesthetically unpleasing and troublesome. More importantly, two main limitations of the invasive techniques are painful process and cost, because constant monitoring of glucose level is very expensive. Therefore, these limitations gave a big boost to researchers for development of non-invasive method for the continuous monitoring of blood glucose because it presents major advantages over existing invasive methods. The proposal to use a laser pointer will be pointed to pass through the urine sample to get the glucose level. This method is supposed to be quick and easy. The cost of the proposed test equipment will be significantly lower than existing methods because it only uses a laser pointer and urine samples from subjects only. In addition, the number patient for this method is expected to be high because it painless, low cost, and rapid.

2. Methodology

Refraction occurs when light is passing from one medium to another medium with different refractive index and develop a bending wave. The waves move at different speeds and through various medium, (example; air and water) depending on their respective density. The denser medium, slower waves travel through the medium. The speed at which light will pass through medium wave measured in the refractive index, n, medium. It is based on the rate of speed of light in vacuum and the speed of light in a medium intrigue. Snell's law is the formula that can be used to describe the relationship between the angle of incidence and angle of refraction when the refraction or some of the light waves bend when it moves from one medium to another.

The proposed non-invasive measurement device that has been developed is inexpensive and portable without compromising its functionalities in implementing measures glucose levels automatically and painless. The non-invasive measuring device consists of a main component which is a laser pointer, cube, and smartphone camera. Each one of the components have their own function which allows the measuring device to carry out the experiment as a whole. All the components will be arranged in which the sample tests will be carried out. The composition of the components in the container began with a laser pointer as light source and the laser beam was refracted into the prism containing the sample. Then, the image of refracted in a cube is captured by a smartphone camera to process the image by using Matlab software. The schematic diagram of the developed system is shown in **Figure 1** and **Figure 2**.

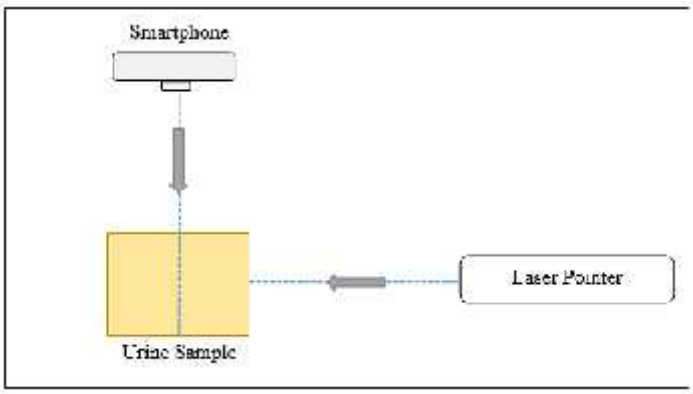

Figure 1: Schematic diagram of the laser glucometer

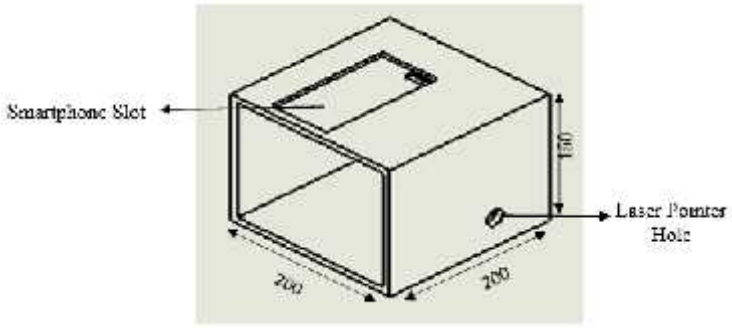

Figure 2: Isometric View of System Design (dimension in mm)

The system was calibrated between sugar concentration and refractive index. This is because the system is developed to prove that the theory of the refractive index is the best way that could be used to find a reading of glucose in the urine. For preliminary experiment, glucometer was used to measure the sugar concentration in the blood. The glucometer reading in millimoles/litre (mmol/l) unit. However, the mass of sugar used in necessary to make the sugar syrup. Hence, the sugar concentration was converted from millimoles/litre (mmol/l) unit to milligrams/decalitre (mg/dL). Based on **Table 1**, range between 1.8 – 2.5 mmol/l is a low glucose reading while the 5.6 – 6.9 mmol/l of glucose readings in the normal range and 15.9 - 22.0 mmol/l glucose readings that are high. therefore, 7.9 mmol/l were used as a starting point in this experiment because it is out of the normal range.

Table 1: Range of Level Sugar Concentration (According to Contour TS Glucometer Device)

Level Sugar Concentration	Range (mmol/l)
Low	1.8 – 2.5
Normal	5.6 – 6.9
High	15.9 – 22.0

During the experiment, mass balance scale was used to measure mass of sugar. The accuracy of mass balance scale is +/- 0.001 g. An increment of each 1 mmol/l of glucometer reading is equal to 18 mg/dL of sugar concentration and equal to 0.018 g mass of sugar when dissolved with 100 ml of water. Results of the preliminary experiments are given in **Table 2**.

Table 2: Results of Preliminary Experiment

Glucometer Reading Sugar Concentration (mmol/L)	Sugar Concentration (mg/dL)	Mass of Sugar (g)	Refraction angle (Degree)	Refraction Angle (Radian)	Refractive Index
7.9	142	0.142	9.739	0.170	4.522
8.9	160	0.160	9.631	0.168	4.573
9.9	178	0.178	9.408	0.164	4.680
10.9	196	0.196	9.392	0.164	4.688
11.9	214	0.214	9.302	0.162	4.733
12.9	232	0.232	9.276	0.162	4.746
13.9	250	0.250	9.028	0.158	4.875
14.9	268	0.268	8.896	0.155	4.947
15.9	286	0.286	8.820	0.154	4.989
16.9	304	0.304	8.711	0.152	5.051
17.9	322	0.322	8.531	0.149	5.157
18.9	340	0.340	8.326	0.145	5.283
19.9	358	0.358	8.275	0.144	5.315
20.9	376	0.376	8.131	0.142	5.409
21.9	394	0.394	8.130	0.142	5.409

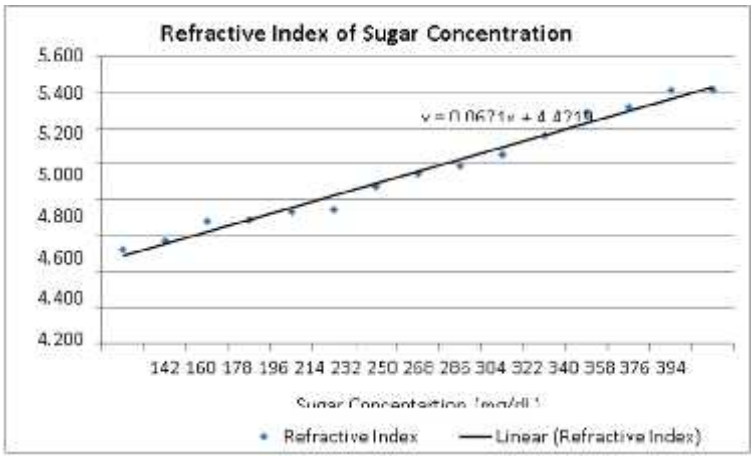

Figure 3: Graph of Refractive Index of Sugar Concentration

Figure 3 shows the refractive index of sugar concentration from 142 mg/dL to 394 mg/dL. The horizontal axis presents the sugar concentration in mg/dL unit and the vertical axis shows the refractive index. The refractive index was calculated by using equation 4 in Chapter 3. The graph indicates that the refractive index increase linearly with sugar concentration. A regression analysis of these data calculates that the equation of the best fit line is $y = 0.0671x + 4.4219$. An R^2 of 0.98 means that 98% of the variance in the data explained by the line and 2% is due to unexplained effects. In contrast, the major limitation of the system is an inaccuracy of the mass balance during mass sugar measurement. The sensitivity of instrument is low due to limited decimal places on digital reading scale.

Expanding the concentration of sugar in water has affected the density and nuclear interactions on the water and has expanded the index of refraction. The refractive index values regularly determined in standard temperature. A higher temperature means sugar concentration becomes less dense and less viscous, causing the light to move more quickly in the medium. A lower temperature means sugar concentration becomes denser and has a higher viscosity, causing the light to move more slowly in the medium.

3. Results and discussion

A urine glucose test determines whether or not glucose (sugar) is present in the urine. Glucose will overflow into the urine when the blood glucose level is high for the kidneys to stop it spilling over into the urine. Urine glucose test was carried out on 4 peoples to measure their glucose level. Firstly, they are required to fast for at least 6 hours before carrying out a urine glucose test. This is because the nutrients and ingredients in foods and beverages consumed will be absorbed into the bloodstream and can affect the accuracy of the glucose level reading. Next step is the glucose level reading was determined first by pricked their finger using sharp needle to get a drop of blood and measures glucose level using glucometer device. The glucometer reading was compared with refractive index of urine.

Table 3: Measurement results

Sample	Glucometer Reading	Refractive Index (Degree)	Refractive Index (Radian)	Refractive Index
1	4.1	9.856	0.172	4.469
2	4.7	9.246	0.161	4.761
3	5.0	8.531	0.149	5.157
4	5.8	8.354	0.146	5.265

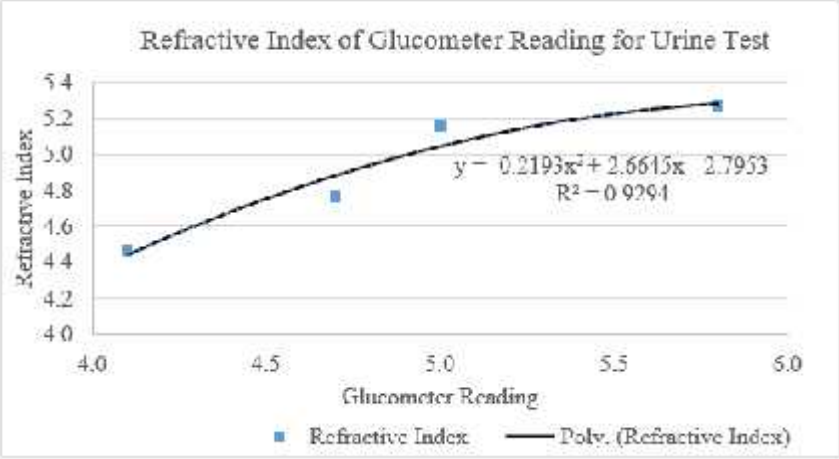

Figure 4: Graph of the refractive indices versus glucometer readings

The graph shows the refractive index of glucometer reading from 4.0 mmol/l to 6.0 mmol/l. The horizontal axis presents the glucometer reading in mmol/l unit and the vertical axis shows the refractive index. The refractive index was calculated by using equation 4 in Chapter 3. The graph indicates that the refractive index increase when the glucometer reading increase. A regression analysis of these data calculates that the equation of the best fit line is y = -0.2193x2 + 2.6645x - 2.7953. An R^2 of 0.93 means that 93% of the variance in the data explained by the line and 7% is due to unexplained effects. The graph is in polynomial compared to graph of refractive index of sugar concentration which is linear graph. This is because due to limited sample. Not many people volunteered their urine as a sample test. Besides, it is ethically difficult to get the urine sample of diabetic patients from hospital and clinic.

Ketones are created regularly by the liver as a major aspect of unsaturated fat digestion. In ordinary expresses, these ketones will be totally processed. On the off chance that for any reason, the body can't get enough glucose for energy it will change to utilizing body fats, coming about ketone creation increment making them distinguishable in the urine. (Sarah et. al, 2017). Something else, a urine glucose test does not reflect blood glucose level at the time of testing. Rather it gives a sign of blood glucose level at the time of testing. For instance, a portion of the urine present in bladder might be 2 hours old, and may demonstrate glucose despite the fact that blood glucose might be standardized since them. That is the reason, the refractive index of urine glucose test need to contrast with a current blood glucose level reading.

The results of a urine glucose test are impacted by the volume and concentration of urine, which will shift with the amount of fluid be consumed and the fluid loss because of such things as heavy sweating or vomiting. Besides, a few medications may interfere withe result s of urine glucose testing. Not just that, the utilization of food and drinks can likewise bring about errors in the results of urine glucose tests. Therefore, they are required to fasting before performing urine glucose test.

4. Conclusions

Nowadays, all existing methods of home glucose level requiring obtaining a blood sample by pricking a fingertip with a needle or lancet to draw blood, then placing the coated strip into glucometer reading. This method strongly discourages patients and causes their finger constantly in a state of wounded because they have quite slow level in wound healing. Furthermore, the invasive technique is not good because it is expensive and painful. The concept of non-invasive technique to measure body glucose level are studied. The effectiveness and functionality of this urine glucose experiment device was proved through the sugar concentration experiment (preliminary experiment). The relationship between the refractive index and sugar concentration was investigated. The refractive index increases rapidly due to the sugar concentration increase. A regression analysis of these data calculates that the equation of the best fit line is y = 0.0671x + 4.4219. An R^2 of 0.98 means that 98% of the variance in the data explained by the line and 2% is due to unexplained effects. Finally, this non-invasive technique is performed well when the refractive index of urine was correlated with the actual reading of blood glucose level measured using a glucometer. The graph indicates that the refractive index increases when the glucometer reading increases. A regression analysis of these data calculates that the equation of the best fit line is y = -0.2193x2 + 2.6645x - 2.7953. An R^2 of 0.93 means that 93% of the variance in the data explained by the line and 7% is due to unexplained effects.

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