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Development of a Non-Invasive Blood Glucose Measurement Device Using the Wheatstone Bridge Method Based on Arduino

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Abstract
Monitoring blood glucose levels in the body of Diabetes Mellitus (DM) patients regularly is an essential part of managing blood sugar levels, which can improve the quality of life for DM patients. One approach in health technology for non-invasive blood glucose detection is through the use of the patient's urine. In this study, a blood glucose measurement device was designed using Arduino Uno, a Wheatstone bridge circuit, a voltage amplifier, and a 16x4 LCD to display the measurement results. The measurement process involves placing a urine sample on one arm of the Wheatstone bridge circuit, where two copper electrode cells are positioned. Changes in the output voltage of the bridge circuit result in a voltage variation, which is then amplified by the voltage amplifier, allowing it to be read by the Arduino. The measurement results indicate that the Wheatstone bridge method can be used to detect glucose in urine, with changes in voltage observed for each tested urine sample.

Keywords: DM, Urin, Jembatan Wheatstone, Arduino.

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INTRODUCTION

The Wheatstone bridge circuit was proposed by Samuel Hunter Christie in 1833 and later popularized by Sir Charles Wheatstone in 1843 [1]. Generally, this circuit consists of four resistors (R1, R2, R3, and R4) arranged in a diamond shape [2]. The basic principle of the Wheatstone bridge is balance, where electrical current flows towards the lower polarity. If there is equal polarity between two points, no current will flow between them, as shown in **Figure 1**.

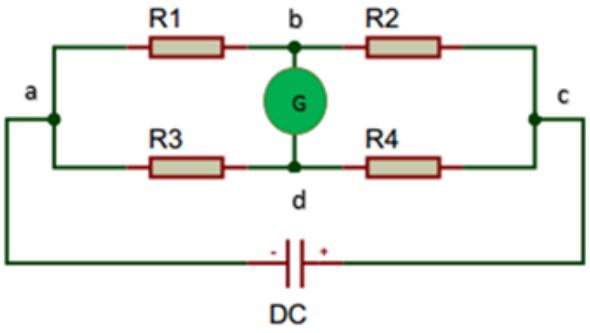

Figure 1. Wheatstone Bridge Circuit

In the Wheatstone bridge circuit, if the potential difference across the galvanometer is zero, the product of the opposite resistances is equal, i.e., R4×R1=R3×R2R4 \times R1 = R3 \times R2R4×R1=R3×R2. The Wheatstone bridge can be utilized as a resistance sensor by replacing one arm of the circuit with components such as an RTD for temperature sensing [3], [4], [5], a strain gauge for measuring water flow pressure [6], or a load cell for weight measurement [7]. In this study, the

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Wheatstone bridge circuit is used as a resistance sensor by substituting one arm of the bridge with two electrodes, which are then immersed in urine.

Urine, also known as urinary fluid, is a waste product excreted by the kidneys and eliminated from the body through the process of urination [8]. Urine serves the function of removing waste substances such as toxins and medications from the body. It is through urine that various diseases can be detected, such as kidney damage, urinary tract infections, dehydration, and other illnesses *diabetes mellitus* (DM). DM is a group of metabolic diseases that arise in an individual due to elevated blood glucose levels resulting from a progressive decrease in insulin secretion [9], [10], [11]. DM can be diagnosed through urine testing by examining urine glucose levels [12]. Urine glucose is one of the methods used for this purpose *non-invasive* which utilizes biofluid techniques to determine glucose levels without causing pain to the body members [9], [13].

Several studies on glucose levels in urine have been conducted using spectroscopic methods, utilizing near-infrared (NIR) light and photodiodes [14]. Research employing optical shift techniques from fiber sensor methods has also been explored [10], [13], [15]. From the descriptions of these studies, it is evident that research on measuring glucose levels in urine is crucial, especially using resistance methods, to develop a measuring device that is safe, comfortable, and compliant with health standards.

METHOD

Overall, the design of the non-invasive urine glucose measurement device refers to the block diagram in **Figure 2**.

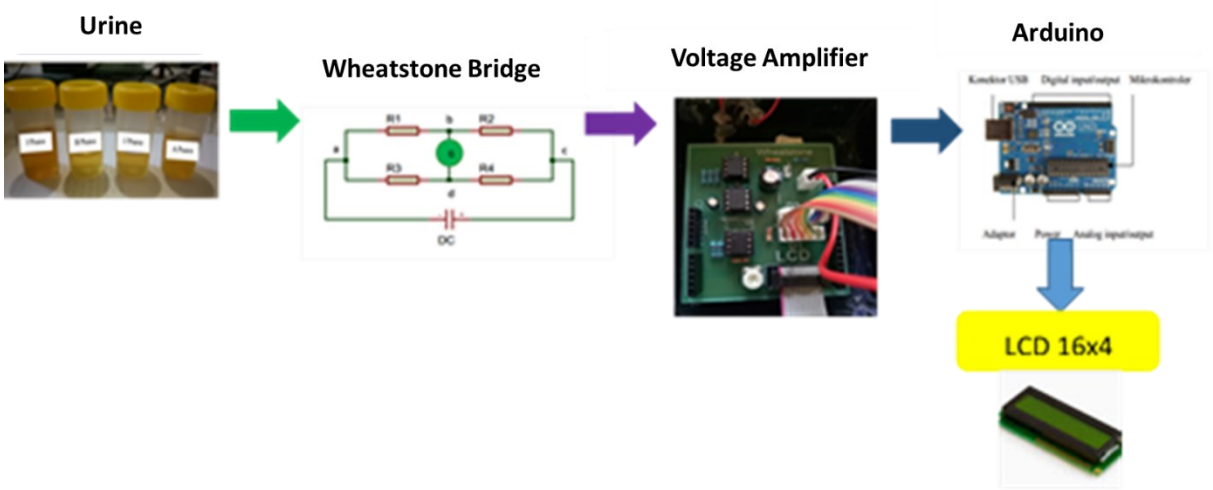

Figure 2. Block Diagram of the Urine Glucose Measurement Device

The design of the blood glucose measurement device consists of fasting urine and random urine as the materials to be measured for glucose levels. The Wheatstone bridge circuit is used as a resistance sensor by replacing the value of R3 in one arm of the bridge with two electrodes, which are then immersed in the urine. A voltage amplifier, Arduino for data processing, and a 16x4 LCD display for output data are also utilized. The measurement begins when the urine is placed into the urine container, and the container is tightly closed, allowing the two electrodes placed on the lid to come into contact with the urine, as shown in **Figure 3**.

The resistance measurement results are in the form of voltage data (mV), which is then converted into glucose levels in urine with units of (mg/dl). The measurement results are later compared with the laboratory results. The conversion is performed using the **Equation 1** as follows [16], [17]:

$$\frac{X-X_1}{X_2-X_1} = \frac{Y-Y_1}{Y_2-Y_1} \quad (1)$$

Description:

X_1 = Voltage for normal urine (-)

X_2 = Voltage for urine of the highest diabetes patient (++++)

Y_1 = Value of normal urine based on laboratory results in mg/dl

Y_2 = Value of urine from the highest diabetes patient (++++) based on laboratory results in mg/dl.

Figure 3. Realization of the Urine Glucose Measurement Device

RESULT AND DISCUSSION

Results of Glucose Level Measurement in Urine Using the Instrument

The measurement results of glucose levels in fasting urine and random urine are shown in **Table 1**.

Table 1. Results of Fasting and Random Urine Measurements

Sampel	Resistance Value (mV)		Urine Glucose Level Value (mg/dl)	
	Fasting	Random	Fasting	Random
A	150	347	79.37	275.34
B	161	353	261.9	293.49
I	200	539	1,000	1,000
J	142	239	0	0

Based on the measurements in **Table 1**, it can be concluded that there is a significant variation between the resistance values (mV) and urine glucose levels (mg/dl) in fasting and random conditions for each sample. Samples A and B showed a substantial increase in both resistance values and urine glucose levels from fasting to post-meal conditions, with Sample A experiencing an increase in glucose levels from 79.37 mg/dl to 275.34 mg/dl, and Sample B from 261.9 mg/dl to 293.49 mg/dl. In contrast, Sample I exhibited extremely high glucose levels, 1,000 mg/dl, both in fasting and post-meal conditions, indicating a potential glucose metabolism disorder. Sample J, on the other hand, showed no detectable glucose in the urine, either in fasting or random conditions, suggesting normal conditions or well-controlled glucose metabolism.

Lab Test Results of Fasting Urine and Random Urine

The non-invasive blood sugar level measuring instrument made is expected to be an alternative measuring instrument for measuring blood sugar levels with urine samples. Therefore, the same fasting urine and random urine samples were tested at the Dr. Moh. Anwar Hospital Laboratory and Fortuna Laboratory, Malang, Indonesia using the dipping analyzer system.

Table 2. Lab Test Results of X from Fasting and Random Urine

Parameter	Results				Normal Value
	Fasting		Random		
	A	B	A	B	
Protein	Positive 1	Negative	Positive 2	Negative	-
Glucose / Reduction	Positive 2	Positive 3	Positive 3	Positive 3	-
Urobilinogen	Negative	Negative	Negative	Negative	-
Bilirubin	Negative	Negative	Negative	Negative	-
Ketone	Negative	Negative	Negative	Negative	-
Nitrite	Negative	Negative	Negative	Negative	-
Eritrosit	0-1	0-1	0-1	0-1	0-1/pb

Parameter	Results				Normal Value
	Fasting		Random		
	A	B	A	B	
Lekosit	0 – 2	0-2	1-2	0-2	0-2/pb
Epithet	1-2	0-2	2-4	0-2	0-2/pb
Kristal	Negative	Negative	Negative	Negative	-
Others	Bacteria +	Negative	Bacteria +	Negative	-
PH	6.0	7.0	8.0	7.0	5.0-8.0
Specific Gravity	1.010	1.010	1.015	1.010	1.010 – 1.030
Color	Yellow	Yellow	Yellow	Yellow	-
Turbidity	Slightly Cloudy	Clear	Slightly Cloudy	Clear	-

Based on the fasting urine measurement results listed in **Table 1**, compared with the laboratory test results in **Tables 2** and **Table 3**, the following results were obtained: Sample A showed a resistance value of 150 mV with a urine glucose concentration of 79.35 mg/dl, diagnosed as positive two (++) indicating the presence of diabetes mellitus (DM). In Sample B, the measured resistance value was 161 mV with a urine glucose concentration of 261.9 mg/dl, resulting in a positive three (+++), indicating DM. Furthermore, Sample I showed a resistance value of 200 mV with a very high urine glucose concentration of 1000 mg/dl, resulting in a positive four (++++) diagnosis, clearly indicating DM. Conversely, Sample J recorded a resistance value of 142 mV with a urine glucose concentration of 0 mg/dl, and the diagnosis was negative (-), indicating that the sample is not affected by DM.

Additionally, in **Table 2**, which contains the random urine measurement results, compared with the laboratory results shown in **Table 3**, the following outcomes were obtained: Sample A showed a resistance value of 347 mV with a urine glucose concentration of 275.34 mg/dl, resulting in a positive three (+++), indicating the presence of diabetes mellitus (DM). For Sample B, the recorded resistance value was 353 mV with a urine glucose concentration of 293.49 mg/dl, and the diagnosis was also positive three (+++), confirming the presence of DM. In Sample I, the resistance value reached 539 mV with a very high urine glucose concentration of 1000 mg/dl, resulting in a positive four (++++), confirming a DM diagnosis. Conversely, Sample J showed a resistance value of 239 mV with a urine glucose concentration of 0 mg/dl, yielding a negative diagnosis (-), indicating no signs of DM in the sample.

Table 3. Lab X Test Results for Fasting and Random Urine

Test	Results			
	Fasting		Random	
	I	J	I	J
Blood	++ (50 RBC/µl)	Negative	++ (50 RBC/µl)	Negative
Bilirubin	Negative	Negative	Negative	Negative
Urobilinogen	Negative	Normal (0.1 mg/dl)	Normal (0.1 mg/dl)	Normal (0.1 mg/dl)
Ketone	Negative	Negative	Negative	Negative
Glucose	++++ (1000 mg/dl)	Negative	++++ (10000 mg/dl)	Negative
Protein	++ (100 mg/dl)	Negative	++++ (100 mg/dl)	Negative
Nitrite	Negative	Negative	Negative	Negative
Leukocytes	+ (25 WBC/µl)	Negative	+ (25 WBC/µl)	+ (25 WBC/µl)
Acidity	5.5	5.5	5.5	6.0
Specific Gravity	1.025	1.025	1.025	1.025

From the explanation above, it can be seen that the measurement results using the glucose urine measurement device developed have met and are almost identical to the standard values of health laboratory tests. The criteria are as follows: (-) = 0 mg/dl, no DM; (+) = 1 mg/dl to 50 mg/dl, indicating DM; (++) = 51 mg/dl to 100 mg/dl, indicating DM; (+++) = 101 mg/dl to 300 mg/dl, indicating DM; (++++)= 301 mg/dl to 1000 mg/dl, indicating DM. The resistance value, in the form of voltage (mV), also doubled between fasting urine samples and random urine samples. Fasting urine has a voltage range of approximately 142-200 mV, while random urine has a voltage range of approximately 239-539 mV. This indicates that fasting urine has already been contaminated by beverages and food ingested by the body.

Discussion

Based on the results of the glucose urine measurements using the developed measuring device and compared with standard laboratory test results, it can be observed that the device shows a good correlation. The measurement results for fasting and random urine samples show a significant

difference, with glucose levels and resistance values (mV) in random urine being higher than in fasting urine. This difference is caused by the contamination from food and beverages that have been ingested by the body, which significantly affects the glucose levels in the urine [6], [18], [19].

When compared to previous studies, the results of this study demonstrate a good alignment with the established laboratory test standards. For instance, a study by Ruciyanti and Sumanto [20], on the use of portable devices for measuring urine glucose levels showed that this method has high accuracy, with a correlation coefficient of 0.98 between the portable device and laboratory test results. This is in line with the findings of this study, where the diagnostic results using the developed urine glucose measurement device showed similarity with laboratory results in identifying diabetes mellitus (DM) based on the defined urine glucose categories, such as (-) for 0 mg/dl, (+) for 1-50 mg/dl, (++) for 51-100 mg/dl, (+++) for 101-300 mg/dl, and (++++) for 301-1000 mg/dl. Another study by Pan and Makinwa [21] also found that portable urine glucose measurement devices could provide accurate and rapid results, allowing for use outside the laboratory with a very low error rate. Moreover, the difference in resistance values between fasting urine and random urine in this study is consistent with the findings of Zonta et al. [22], who showed that glucose levels in random urine tend to be higher due to the influence of food and beverages ingested by the body, which affects the resistance measurement results. This suggests that the device used in this study is adequate for accurately measuring urine glucose levels and has the potential to be used for early DM detection outside the laboratory.

AUTHOR DECLARATION

Author contributions and responsibilities - The authors made major contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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CONCLUSION

Based on the results of the study, the following conclusions can be drawn: This study successfully developed a non-invasive blood glucose measurement device using urine samples as test materials. The resistance measurement results, in the form of voltage (mV), obtained using the non-invasive blood glucose measurement device through the Wheatstone bridge method, showed that fasting urine had values ranging from 142-200 mV for individuals with DM, while random urine had values ranging from 239-539 mV for individuals with DM. The test results from the non-invasive blood glucose measurement device using the Wheatstone bridge method met the health laboratory testing standards, with individuals diagnosed with DM indicated by positive symbols (+), (++), (+++), (++++) and those without DM indicated by the negative symbol (-).

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