Project Report: Non-Invasive Blood Glucose Meter

Presented by: Zeeshan Haider (424689),Aized Soban(414175),Abdullah Mir(407857)
Instructors: Ma'am Qurat-ul-Ain , Sir Qazi Waqas

Abstract

This project focuses on designing and constructing a non-invasive blood glucose meter to address the discomfort and complications associated with traditional glucose monitoring methods. The device employs the Beer-Lambert principle using a reflective optical sensor to measure blood glucose levels by analyzing light absorption. With a system comprising signal detection, analog signal conditioning, digital signal processing, and an LCD display, the device provides accurate glucose readings with a mean absolute percentage error of 10-15%.

Introduction

Diabetes is a prevalent condition affecting millions worldwide. Accurate monitoring of blood glucose levels is vital for managing disease and preventing complications such as chronic kidney disease, neuropathy, and cardiovascular issues. However, traditional glucose monitoring methods require frequent invasive sampling, causing pain and reducing patient compliance. This project aims to overcome these issues by developing a non-invasive blood glucose meter that is accurate, convenient, and user-friendly.

Objective

- Design a non-invasive device to measure blood glucose levels using optical technology.
- Ensure the device provides accurate readings and is easy to use for daily monitoring.

Basic Concept

The non-invasive blood glucose meter operates on the **Beer-Lambert Law**, which states that the absorbance of light is proportional to the concentration of the absorbing substance (glucose). The device uses near-infrared light (950 nm), which penetrates the skin and interacts with glucose in the bloodstream. A reflective optical sensor captures the reflected light, and the signal is processed to determine glucose levels.

System Design

The device is divided into four main components:

1. Signal Detection

- **Sensor**: TCRT1000 reflective optical sensor.
    - Near-infrared LED emits light absorbed by glucose.

- Phototransistor detects the reflected light.

- **Pressing Status Circuit**: Ensures consistent pressure on the sensor to avoid inaccurate readings.

2. Analog Signal Conditioning

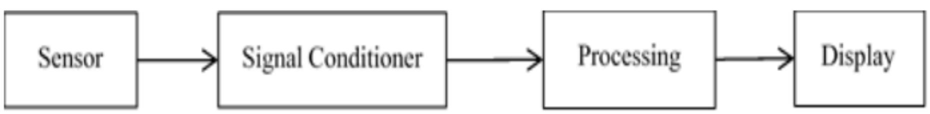
- **Amplification**: A non-inverting AC amplifier (LM358) enhances the small voltage signals.
- **Filtering**: High-pass and low-pass filters remove noise and unwanted frequencies.

3. Digital Signal Processing

- **Microcontroller**: Arduino UNO R3 converts the analog signal into digital data and applies a calibration equation to determine glucose levels.

4. Display

- A 16x2 LCD shows the blood glucose concentration in mg/dL.

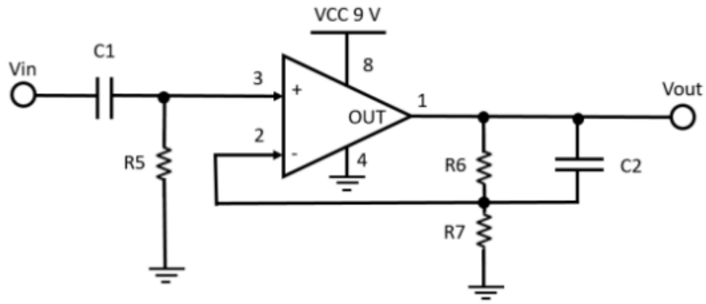


Circuit Description and Operation

Circuit Overview

The non-invasive blood glucose meter circuit integrates multiple subsystems, including:

1. **Sensor Circuit**:
   - The TCRT1000 reflective optical sensor consists of a near-infrared LED and a phototransistor.
   - A 9V DC power supply drives the sensor, with resistors limiting the current to prevent damage to the LED and phototransistor.
   - The reflected light intensity is converted into a voltage signal by the phototransistor, which serves as the input for further processing.
2. **Pressing Status Circuit**:
   - A micro-switch with red and green LEDs indicates proper sensor contact.
   - The red LED lights up for insufficient pressure, while the green LED confirms optimal contact.
   - This ensures that consistent force is applied to the sensor, minimizing noise and variability in readings.
3. **Amplifier and Filtering Circuit**:
   - A non-inverting amplifier configuration using the LM358 op-amp is employed to amplify the sensor's weak voltage signal.



- The gain is set to 20x by selecting appropriate resistor values in the feedback loop.

$$A_V = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_i} \therefore R_f = R_i(A_v - 1)$$

$$R_6 = 10 \times 10^3 (20 - 1) = 190\ k\Omega$$

- A high-pass RC filter removes low-frequency noise.

$$R = \frac{1}{2\pi f_c C}$$

$$R_5 = \frac{1}{2\pi \times 0.5 \times 0.1 \times 10^{-6}} = 3\ M\Omega$$

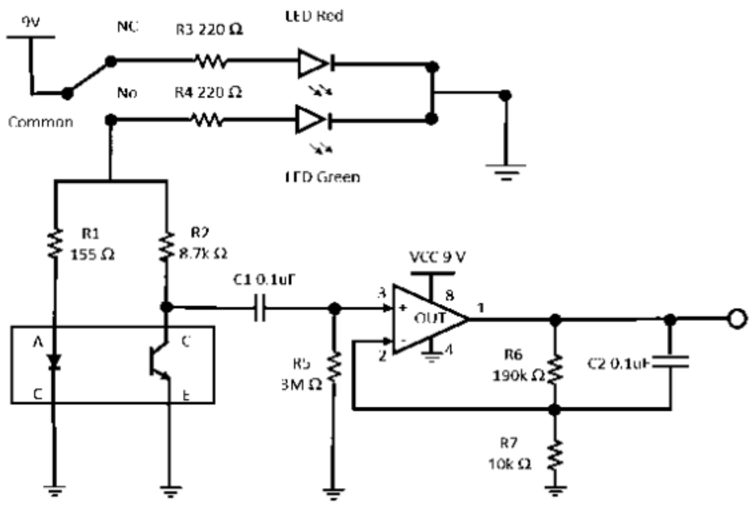
- low-pass RC filter eliminates high-frequency interference, ensuring a clean signal for the microcontroller.

$$C = \frac{1}{2\pi f_c R}$$

$$C_2 = \frac{1}{2\pi \times 2.5 \times 190 \times 10^3} = 0.33\ \mu F$$

4. **Microcontroller Circuit**:
   - The Arduino UNO R3 receives the conditioned analog signal and converts it into digital data using its built-in ADC (Analog-to-Digital Converter).
   - The processed signal is fed into a calibration equation programmed into the microcontroller to compute the blood glucose level in mg/dL.
5. **Display Circuit**:

- The processed glucose value is displayed on a 16x2 LCD screen.
- The microcontroller communicates with the LCD using its digital I/O pins, ensuring real-time feedback to the user.

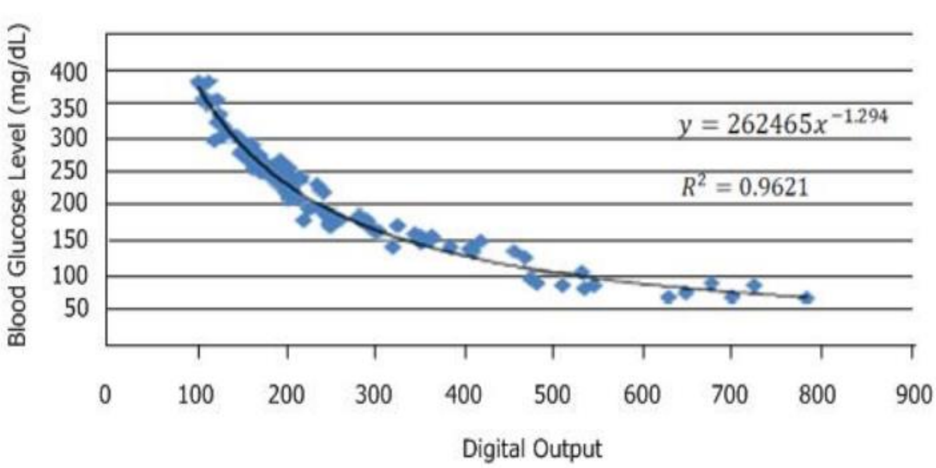


Calibration

- **Data Collection**: Blood glucose levels were measured for 200 participants using standard lab methods and the non-invasive device.
- **Curve Fitting**: The relationship between blood glucose levels and digital output was modeled using an exponential equation:

y=262465·x−1.294y = 262465 \cdot x^{-1.294}

where yy is glucose level (mg/dL) and xx is the digital signal output. The coefficient of determination (R2R^2) was 0.9621, indicating high accuracy.



Experiments(Note: These all experiments were taken from another research conducted by the Preya Anupongongarch [Rangsit University | RSU · College of Biomedical Engineering Rangsit Universit Thailand, Jamie O'Reilly, King Mongkut's Institute of Technology Ladkrabang · Faculty of Engineering Doctor of Engineering, Thawat Kaewgun ,Rangsit University | RSU])

1. Testing of Integrated Circuits

- The output from the sensor circuit was analyzed using an oscilloscope, confirming the signal range was suitable for processing (0–4 V).

2. Functional Testing

- Glucose levels of five participants were measured before and after meals. Results showed trends consistent with the Oral Glucose Tolerance Test (OGTT).

3. Accuracy Testing

- Nine volunteers underwent glucose measurement using both the standard method and the device. The mean absolute percentage error was 10-15%, within the acceptable limit of ±10%.

Subject	Blood glucose level from the standard measuring methods (mg/dL)	Blood glucose level from the non-invasive blood glucose (mg/dL)			Average blood glucose level from the non-invasive blood glucose (mg/dL)	Standard Deviation	error (%)
		1	2	3			
1	80.4	97	90	92	93	3.61	15.67
2	90.2	99	85	82	88.6	9.07	1.77
3	133.9	120	108	119	115.6	6.66	13.67
4	92	87	104	95	95.4	8.50	3.7
5	90	98	80	90	89.5	9.02	0.56
6	84.7	85	100	81	88.8	10.02	4.84
7	88.8	107	84	80	90	14.57	1.35
8	82.8	80	82	89	83.5	4.37	0.85
9	91.7	99	86	80	88.3	9.71	3.71
Average Percentage Error (%)							5.12

Results

- Measurement Range: 80–300 mg/dL.
- Response Time: 5 seconds per reading.
- High accuracy with a mean absolute percentage error of 10-15%.
- Calibration ensured reliability across a broad range of glucose levels.

Advantages

- Painless and non-invasive.
- Real-time glucose monitoring.
- Portable and user-friendly design.
- Reduces risks of infection and discomfort from traditional methods.

Limitations and Future Work

Limitations

- Limited accuracy for glucose levels below 80 mg/dL or above 300 mg/dL due to insufficient calibration data.
- Variability in readings due to inconsistent finger pressure.

Future Improvements

- Enhance the pressing status circuit to ensure consistent pressure.
- Incorporate additional parameters (e.g., pulse rate, age, BMI) for more precise readings.

Conclusion

The non-invasive blood glucose meter is a promising solution for diabetes management, offering a painless, accurate, and convenient method for glucose monitoring. Future enhancements can further improve its usability and accuracy, making it a valuable tool for diabetic patients.

References

1] P. Anupongongarch, T. Kaewgun, and J. A. O'Reilly, "Design and construction of a non-invasive blood glucose meter," International Journal of Applied Biomedical Engineering, vol. 13, no. 2, pp. 36-42, 2020. Available: https://www.researchgate.net/publication/349915699.

[2] D. Bruen, C. Delaney, L. Florea, and D. Diamond, "Glucose sensing for diabetes monitoring: Recent developments," Sensors, vol. 17, no. 8, pp. 1-24, Aug. 2017.

[3] J. Liu, L. Tao, Z. Zhao, et al., "Two-year changes in hyperuricemia and risk of diabetes: A five-year prospective cohort study," International Journal of Endocrinology, vol. 2018, pp. 1-9, 2018.

[4] P. J. Phillips, "Oral glucose tolerance testing," Australian Family Physician, vol. 41, no. 6, pp. 391-393, 2012.

[5] J. S. Krouwer and G. S. Cembrowski, "A review of standards and statistics used to describe blood glucose monitor performance," Journal of Diabetes Science and Technology, vol. 4, no. 1, pp. 75-83, Jan. 2010.