Non-Invasive Glucometer Using NIR and Photoplethysmography

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GlucoPal

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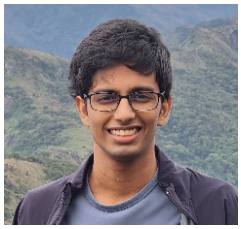

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Near-Infrared-Based Glucometer Proposal

1. Problem being Addressed and Why it is Important

Diabetes, one of the most common chronic diseases that people have throughout their lives, is expected to surpass all other causes of death in the near future. Diabetes is an autoimmune disease brought on by the body's incapacity to control glucose, or sugar, in the body. While diabetes in itself is harmful, improper treatment of diabetes worsens the situation, by harming and causing other delicate organs in the body to malfunction.

According to the International Diabetes Federation (IDF), 540 million adults, or 10.5% of the global population, had diabetes in 2021. Without effective prevention strategies, this number is projected to rise to 783 million (12.2%) by 2045. In the same year, diabetes was responsible for 6.7 million deaths and incurred healthcare costs amounting to $966 billion, marking a staggering 316% increase over the past 15 years. Additionally, an estimated 541 million individuals worldwide had pre-diabetes in 2021, placing them at a high risk of developing type 2 diabetes. The burden of diabetes disproportionately affects low- and middle-income countries, where three out of four individuals with the condition reside, with many remaining undiagnosed.

Sri Lanka, a country with a population of 22 million, is experiencing a steady rise in diabetes and pre-diabetes cases. Currently, 20% of Sri Lankan adults aged 20 to 79 have either diabetes or pre-diabetes, and one-third of those with diabetes remain undiagnosed. Several factors contribute to this rising trend, including an aging population, increasing obesity rates, urbanization, and reduced physical activity. Between 2011 and 2021, the prevalence of type 2 diabetes surged from 7.6% to 11.3%, reflecting a 68.3% increase. [5]

Early detection and ongoing monitoring are essential to preventing complications and lowering healthcare costs, because of the high prevalence of diabetes and its life-altering effects. However, the lack of easily available and reasonably priced screening techniques means that a lot of people go untreated. By creating a novel, non-invasive diabetes detection and monitoring device, our project seeks to close this gap and offer a practical, affordable, and user-friendly way to enhance early diabetes diagnosis and management.

2. Process of Collecting Information about the Problem

We began our research on prevailing issues in the health sector by consulting several medical professionals. Our focus shifted to a specific issue suggested by a pediatric endocrinologist (now acting as our mentor) based on the widespread relevance and influence it has on the healthcare sector; the issue of inconvenience and discomfort presented to diabetic patients, especially children, by the common invasive procedure of measuring blood sugar involving pricking a finger. She emphasized that the issue has been an unaddressed inconvenience in Sri Lanka for a significant time, not only to patients but also to medical professionals like herself.

With an initial idea based on her insights, we expanded our knowledge further by consulting research papers and studies about the issue to better understand the problem. We were able to find a number of studies that recognized this issue [2] [3] [4] [6], and called for the urgent need of an economically feasible and reliable noninvasive procedure/product to measure blood glucose levels. Our research also included an investigation of such possible non-invasive procedures, after which we recognized NIR technology and PPG waveforms as two of the most promising procedures, and decided to develop GlucoPal based on them.

3. Brief Description of the Solution

Overview

Diabetes management relies on accurate blood glucose monitoring, which is traditionally done through invasive blood sampling via pricks. Pricking is often painful, requires expensive test strips, and is not a viable option for continuous glucose monitoring.

This project aims to develop a non-invasive near-infrared (NIR)-based glucometer utilizing an IR emitter and receiver (940nm) to measure blood glucose levels from the finger. The proposed solution will process photoplethysmographic (PPG) signals and peak IR values to train machine learning models for accurate glucose prediction.

Methodology

1. **Hardware Setup**
    - Use an IR emitter (940nm) and receiver to measure light absorption variations through a fingertip.
    - Process the analog signals from the sensor using a microcontroller.
    - Convert the analog values into a continuous PPG waveform and extract peak values separately.

2. **Signal Processing & Data Collection**
    - The IR receiver will capture light absorption variations corresponding to blood volume changes.
    - The continuous signal will be processed to generate a PPG waveform.
    - Peak IR values will be extracted separately for a secondary data analysis approach.
    - Data will be collected in correlation with actual blood glucose measurements.

3. **Model Training**
    - **PPG Waveform Model:** Trained using the PPG waveform and corresponding blood glucose levels.
    - **Peak IR Value Model:** Trained using peak IR values and corresponding blood glucose levels.
    - Both models will be evaluated and validated using real-world data to enhance prediction accuracy.

Rationale

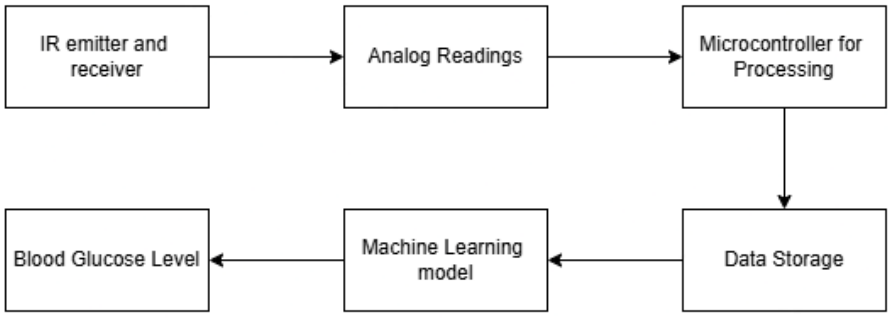
The glucose molecule exhibits its highest absorption peak at 940nm [3], making near-infrared (NIR) sensing at this wavelength suitable for estimating blood glucose levels [7]. However, NIR-based methods alone have demonstrated limited correlation with actual blood glucose levels [3].

To enhance accuracy, we plan to capture Photoplethysmogram (PPG) signals, which measure volumetric blood flow changes using the same sensors. Integration of PPG signals into machine learning algorithms has shown improved predictive capability for blood glucose levels compared to infrared methods alone [3] [6] [8].

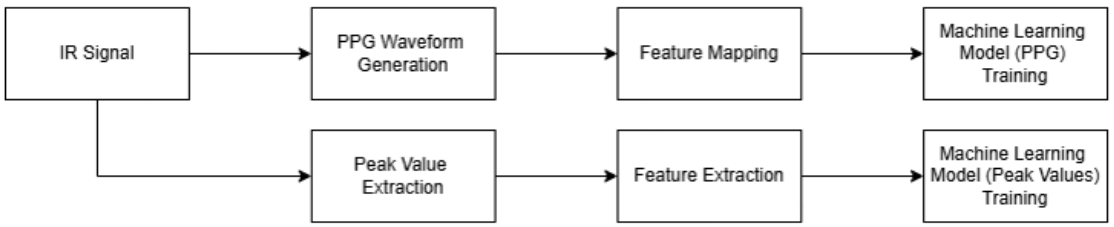
By leveraging both techniques, our goal is to significantly improve the accuracy of our device.

Functional Diagrams

System Architecture



Data Flow



Required Resources

Hardware

- 940nm IR emitter and receiver
- Microcontroller (e.g., Arduino, ESP32, or Raspberry Pi)
- Analog-to-Digital Converter (if required)
- Low Noise Amplifier
- Finger clip for sensor placement
- Power supply and necessary wiring

Software

- Python (for data processing and ML model training)
- Machine Learning frameworks (TensorFlow/PyTorch/Scikit-learn)
- Signal processing libraries (SciPy, NumPy, OpenCV for waveform extraction)

Data

- Collection of paired datasets (PPG waveform and blood glucose levels, Peak IR values and blood glucose levels)
    - Datasets available online
    - Clinical datasets / Volunteer data (if possible)
- Data pre-processing for noise reduction and feature extraction

Novelty and Uniqueness

- **Non-Invasive Glucose Monitoring:** Unlike traditional glucometers, this system eliminates the need for finger pricking.
- **Dual Model Approach:** By using both PPG waveform and peak IR values, the system enhances accuracy and redundancy in glucose prediction.
- **Machine Learning Integration:** Advanced AI models will improve accuracy over time through adaptive learning.
- **Real-Time Monitoring Potential:** The system can be extended for continuous glucose monitoring, benefiting diabetic patients with real-time data insights.

Market Analysis & Competitor Landscape

During our discussions with doctors, a critical pain point became evident: the traditional pricking method for glucose monitoring is far from ideal. It presents several challenges:

- **Pain & Discomfort:** Patients dislike the frequent finger pricks.
- **High Cost:** Test strips are expensive, making long-term use burdensome.
- **Limited Feasibility for Continuous Monitoring:** The method is impractical for real-time glucose tracking.

Recognizing these challenges, we conducted in-depth research and identified a significant market opportunity. While non-invasive glucose monitoring solutions are available globally, they are not widely used in Sri Lanka. Doctors confirmed that the high cost of existing solutions makes them inaccessible to most of Sri Lanka's population.

This gap provides a unique first-mover advantage for us. By offering an affordable and accessible alternative, we can redefine glucose monitoring in Sri Lanka's healthcare sector, making it feasible for both hospitals and individual patients.

Existing Products

Right now, there aren't many non-invasive glucometers on the market. This is mainly because it's hard to make accurate predictions. Some devices do exist, but they have major drawbacks. For example, sugarBEAT [1] measures glucose using interstitial fluid (ISF), but ISF sugar levels lag behind the actual blood glucose levels by 4-10 minutes [2].

Other non-invasive glucometers also struggle with accuracy, ease of use, and consistency. Many of them use complex methods that don't give results as reliable as traditional finger-prick tests.

Another big issue is cost. Most of these devices are very expensive, making them impractical for markets like Sri Lanka. Because of this, there's still a big need for an affordable and accurate non-invasive glucometer in the country.

4. Impact of the Solution on Healthcare

Impact on the Healthcare Sector

The introduction of a non-invasive glucometer based on Near-Infrared (NIR) sensing and Photoplethysmography (PPG) has the potential to revolutionize diabetes management in Sri Lanka and beyond. The healthcare sector, particularly in developing countries, faces multiple challenges in glucose monitoring, including high costs, limited accessibility, and patient discomfort with invasive methods. GlucoPal directly addresses these issues and provides significant benefits to multiple stakeholders, including patients, healthcare providers, and the government.

Sustainability of GlucoPal

GlucoPal enhances sustainability by eliminating the dependence on disposable test strips, which contribute significantly to medical waste. Traditional glucose monitoring requires frequent pricking, leading to biohazardous waste and ongoing expenses. Our device, by utilizing Near-Infrared (NIR) technology and Photoplethysmography (PPG), removes the need for invasive procedures, reducing both environmental impact and healthcare costs. Additionally, the device is designed for long-term use with rechargeable batteries and durable components, ensuring minimal replacement needs. This approach not only minimizes medical waste but also provides a reliable, low-maintenance alternative for continuous glucose monitoring, making it a more sustainable choice for diabetes management.

How GlucoPal Addresses the Problem Statement

Diabetes management relies heavily on frequent blood glucose monitoring, which is traditionally invasive, painful, and costly. GlucoPal directly addresses these challenges by leveraging Near-Infrared (NIR) technology and Photoplethysmography (PPG) to measure blood glucose levels non-invasively. This removes the need for frequent finger pricking, making it more comfortable for users while eliminating the recurring cost of test strips. Additionally, machine learning integration enhances accuracy over time, ensuring reliable glucose level estimation. By providing a practical alternative to conventional methods, our device enables better diabetes management without the drawbacks of invasive testing.

How Customers Will Benefit from GlucoPal

- **Pain-Free Monitoring:** Eliminates the need for finger pricks, providing a more comfortable experience for diabetic patients.
- **Cost-Effective:** Reduces the financial burden by eliminating the need for costly test strips, making glucose monitoring more affordable.

- **Increased Accessibility:** Offers a practical solution for diabetes patients in Sri Lanka who struggle with the high cost of traditional glucometers.
- **Continuous Monitoring:** Enables real-time glucose tracking without discomfort, leading to better disease management and early intervention.
- **Improved Healthcare Efficiency:** Reduces the financial strain on healthcare institutions by offering a non-invasive alternative to traditional glucose testing.
- **Better Long-Term Health Outcomes:** Encourages frequent monitoring, helping patients manage their condition more effectively and reduce complications.

5. References

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[7] https://sci-hub.se/https://doi.org/10.1109/ICAC49085.2019.9103375

[8] https://www.mdpi.com/2076-3417/14/4/1406