A Portable Solution to Noninvasive Glucose Sensing with Light

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ABSTRACT

Previous work by Li et al.[5] has shown promising results in sensing blood glucose levels using polarized light. In this paper, we miniaturize the glucose sensing prototype into a portable device. The process of prototype miniaturization has revealed challenges in dealing with specular reflected light caused by multiple reflections within the sensing box. We propose a new structural design that traps the light inside a chamber. Our preliminary results with a single user without diabetes over 5 days showed a 9.5% mean absolute relative difference (MARD). For this participant, 92% of our results are clinically accurate (within Zone A) and the remaining are clinically acceptable (within Zone B) of the Clarke Error Grid.

CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile computing**; • **Hardware** → **Sensor devices and platforms**.

KEYWORDS

Noninvasive glucose sensing, light sensing, polarization

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1 INTRODUCTION

Diabetes is a chronic health condition effecting more than 10% of people in the United States[3]. Imbalance between insulin needs and insulin supply results in abnormal blood glucose levels (BGL) in the effected people potentially leading to complications, including heart disease, stroke, and kidney failure if improperly managed. It is crucial for people with diabetes to keep track of their BGL and modify dosing of blood sugar-lowering medications when necessary. Off-the-shelf products such as finger stick test strips and continuous glucose monitors (CGM) can be used to measure a person's BGL. They are however expensive, invasive, and inconvenient; the finger stick test requires a small blood sample to be drawn each time a test is performed and the CGM inserts a sensor transdermally into the tissue space and must be changed every 7-14 days. Therefore, a noninvasive, accurate, durable, and portable glucose sensor is highly desirable to patients with diabetes.

Li et al. [5] uses optical polarimetry to measure optical rotation that is linearly related to the glucose concentration of the interstitial fluid inside the skin. We extend their work by reducing the size of the prototype into a more portable device. During the process of miniaturizing the prototype, we face challenges in dealing with the specular reflection. When a linearly polarized light beam reaches the skin, 2% of the light enters the skin, reemits with the polarization preserved[4], and reaches the sensor. On the other hand, 5% of the light is specular reflected right away without interacting with the glucose molecules inside the skin. It then bounces off the wall inside the enclosure and reaches the sensor as noise. Therefore, we propose a new structural design to guide the light away from the sensing component and trap it inside a chamber.

2 SYSTEM DESIGN

The main bottleneck of miniaturization is the size of the liquid crystal (LC). With a small LC (1.27cm×1.27cm), the current sensing box is measured in 8cm×7.5cm×3.5cm, significantly reduced from out prior prototype (19cm × 13cm × 5cm[1]). Figure 1 shows the size comparison between the previous and our proposed prototype.

Three laser diodes of wavelengths 450nm, 520nm, and 658nm, and a photodiode are placed inside a small enclosure. Since multiple reflections occur within the enclosure, some of the light reaches the photodiode without interacting with the skin. The light does not pass through the glucose molecules inside the skin and hence it becomes noise. We can use light-absorptive material to absorb the reflected light but some are still scattered from the material surface. Therefore, we design a chamber with an absorptive coating to trap the reflected light. This chamber allows the light to bounce around multiple times so that it can be sufficiently absorbed by the material; see Figure 2.

Overall, the whole system consumes 160mW during sensing and 60mW when idle. The idle power consumption can be further reduced by disabling the electronic components on the circuit board.

[1]This is the dimension of the previous sensing box. It is incorrectly reported as 17cm × 10cm × 5cm in [5]

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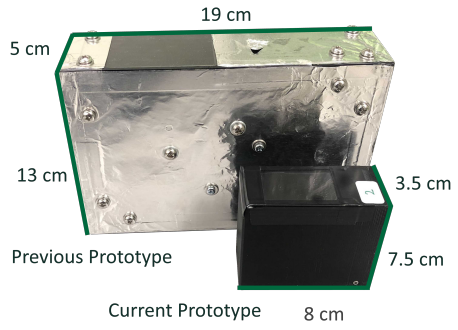

Figure 1: Size comparison between the previous prototype and the current prototype

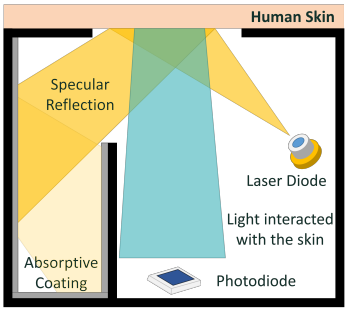

Figure 2: Light trap mechanism used to guide the specular light away from the sensor

3 PRELIMINARY RESULT

Using the new sensing box, we collect 216 samples from a single user without diabetes over 5 days. The ground truth is collected with the Freestyle Libre 2 CGM. An XGBoost machine learning model is trained and the result is analyzed using leave-one-out cross-validation. We evaluate our system by computing the absolute relative differences (ARD) as shown below:

$$\text{ARD} = \frac{|\text{predicted glucose} - \text{reference glucose}|}{\text{reference glucose}} \quad (1)$$

We achieved a 9.5% mean absolute relative difference (MARD), which is comparable to the prior prototype with a larger form factor. We also plot the result on a Clarke Error Grid[2] to evaluate the clinical accuracy of our proposed system; see Figure 3. 92% of our predicted glucose levels are in Zone A which is clinically accurate, and the remaining 8% are in Zone B which is clinically acceptable.

4 DISCUSSION

We collect data from a single user who does not have diabetes, where the BGL was kept within a healthy range. This can not fully reflect the general performance since the difference in skin tones among individuals and the BGL at extreme ranges could affect the performance of the system. Hence, we will conduct a clinical study to collect a larger dataset over a longer period of time from diabetic patients with a diverse user group. Moreover, we are using the CGM

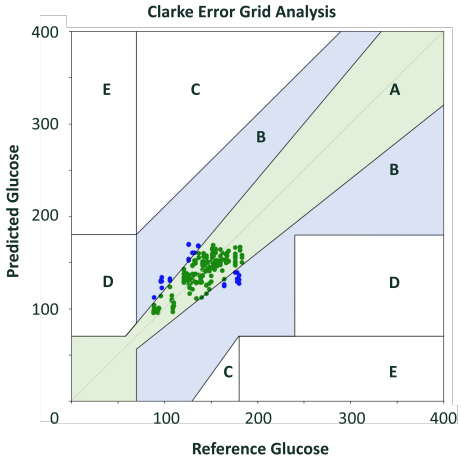

Figure 3: Clarke error grid analysis of our machine learning model. All of our predicted glucose levels are in Zone A (clinically accurate) and Zone B (clinically acceptable).

reading as our ground truth, which measures the glucose level in the interstitial fluid and predicts the BGL. While this allows us to collect more data points for training the machine learning model compared to the traditional finger prick test, the CGM itself has a 9.2% MARD for adults [1], which means the performance of our prototype could be better or worse.

5 CONCLUSION

We extended the previous work by Li et al.[5] by miniaturizing the prototype to a portable form factor. A light trap mechanism is designed to handle the specular light reflection. The system was evaluated by collecting 216 samples from a single user over 5 days and a 9.5% MARD was achieved. Additionally, all the predicted glucose levels were within Zone A and B of the Clarke Error Grid.

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Conflict of Interest Dr Forlenza conducts research supported by Medtronic, Dexcom, Abbott, Insulet, Tandem, Beta Bionics, and Lilly and has been a speaker/consultant/ad board member for Medtronic, Dexcom, Abbott, Insulet, Tandem, Beta Bionics, and Lilly. All other authors report no relevant COI.

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