Project Overview: The Regulators: Glucose Colorimetric Paper Test Strips
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Background:

Diabetes is the group of diseases characterized by excessive blood glucose levels due to the body's inability to produce insulin or the lack of proper usage of insulin. Since diabetes is an incurable and chronic disease, daily blood glucose checkups are vital in ensuring well-being and safety. However, it is difficult for many diabetics in developing countries to manage their disease because there are no means to inexpensively and effectively measure their blood glucose levels. Currently, the most prevalent method is to use a glucometer with one-time-use test strips. Glucometers range from $40 to $60[1] and individual test strips cost between $0.40 to $2.00[2]. Type II diabetics who are not on oral medication are recommended to test blood sugar levels at least once a day, and Type I diabetics may need to test up to six to ten times per day[3]. This financial constraint is especially dire in countries like Uganda, where the average income in Kampala, its largest city and second wealthiest district by GDP per capita, is roughly $300 per month[4].

Proposed Solution:

Our project is centered on glucose colorimetric paper test strips and focused on improving the visual accuracy of the blood sugar determination through indicator experimentation. When glucose is introduced to the strips, a color change occurs and indicates the relative blood glucose and diabetic status of the user. Glucose oxidase, the primary glucose reagent in glucometers, will be used in these test strips to produce gluconic acid and hydrogen peroxide. We used TMB, an indicator used to visually differentiate between different levels of hydrogen peroxide, which should be approximately proportional to blood glucose levels. The glucose oxidase and indicator solutions will be distributed in bottles, from which tests can be conducted dropwise onto strips of A4 copy paper. To complement the colorimetric strips, we created a mobile application that uses camera input and a color analysis algorithm to determine the glucose level (to a reasonable accuracy) based on the color of the strips. The Uganda Bureau of Statistics shows that 86% of 18-30-year-olds own a smartphone and most Kampala households have access to a smartphone so a mobile app is reasonable[5].

This project is an extension from the first iteration by the 2017 EID group[6]. As an extension to their method, we created a fibermesh membrane to filter out plasma from red blood cells to avoid a red color contamination. We also planned to improve the algorithm to filter out some of the red blood color and lighting by using a small blood sample and white paper as color controls.

[1] https://www.webmd.com/diabetes/qa/how-much-do-glucose-meters-cost
[2] http://www.diabetesforecast.org/2012/jul/the-cost-of-test-strips.html
[3] https://www.diabetesselfmanagement.com/blog/type-1-diabetes-vs-type-2/
[4] https://moodle.cooper.edu/moodle/pluginfile.php/72961/mod_resource/content/1/DiabetesManagement-IntroPresentation-9-6-18-v1.pdf
[5] https://www.ubos.org/onlinefiles/uploads/ubos/2014CensusProfiles/KAMPALA-KCCA.pdf
[6] https://minhtyyufa.wixsite.com/gcubedsolutions

Addendum: Notes on the App

The mobile app makes it easy for a user to determine blood glucose level from the test strip: the user points the camera at the image, and clicks the "Analyze" button. The device camera stream will be shown with a guiding marker in the app. A brief how-to guide in the app to help users.

The color detection is a set of heuristics determined by trial and error. The major steps were threshold all of the pixels into clusters (i.e., breaking down the 2^24 color space down to 2^12 clusters), and filtering out clusters based on number of pixels (too few would indicate an insignificant splotch, such as a speck of dust, and too large might indicate a background color), center (the center of the clustered pixels should be near the center of the camera input), error using the "jump method"[7], and color (the dark blue ring was determined to be the best indicator of color, and thus the algorithm biased dark and primarily-blue clusters). The few clusters that remained would be averaged (weighted averaged based on number of pixels per cluster), and the R, G, and B values of this cluster would be put through the inverse trend lines generated by the model (see answer to (2)) to guess at the blood glucose level. The three estimates (one for R, G, and B) would be averaged (weighted based on R^2) to get a final BGL determination. This offers results better than the ones from last year's app because it does not require any user input and can capture more complex patterns (i.e., the rings of color).

The calibration "trials" involved running the heuristic filtering on the samples, and plotting the final cluster against BGL concentration. A trend line was created for each color. (A polynomial trend line worked best, but its end behavior did not make sense; the close-behind logarithmic models seemed more reasonable). Unsurprisingly, the trend line for the blue component was strongest, indicating that the difference between the blue could most reliably be used to determine BGL.

The concentrations of the samples for calibration were known. When the heuristics are performed on these samples, there is some variation. If used correctly and lighting is consistent, the variation in readings of the same sample varied by up to roughly ±30mg/dL. While this may seem like a wide range of error, diabetics' blood sugar levels can range far greater[8], so it should still be a useful metric. With further experimentation, however, it is expected that the the algorithm should improve and variation should decrease, and user error and lighting will be better accounted for.

[7]https://blog.algolia.com/how-we-handled-color-identification/
[8]https://www.joeniekrofoundation.com/stroke-2/3685/attachment/diabetes-blood-sugar-chart/