Glucose Levels in Context – A Mobile Diabetic Assistant

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Abstract
This paper presents GlucoGo, a mobile diabetic assistant that will aid persons in need of easy blood sugar, diet, and exercise tracking tools. It will also provide learning opportunities that promote individual empowerment in managing the disease. GlucoGo is designed to demonstrate lifestyle (diet, exercise, mood) in the context of blood sugar readings such that the diabetic person may learn cause and effect resulting in the adoption of healthier behaviors.

Keywords
Mobile, persuasive technology, healthcare, diabetes

ACM Classification Keywords
H5.m. Information interfaces and presentation

Introduction
Diabetes is a disease that affects approximately 20.8 million people. Though descriptions of the disease and its pathology could fill entire books, the American Diabetes Association offers this concise description: "Diabetes is a disease in which the body does not produce or properly use insulin. Insulin is a hormone that is needed to convert sugar, starches, and other foods into the energy needed for daily life. The cause of diabetes continues to be a mystery, although both genetics and environmental factors such as obesity and lack of exercise appear to play roles." Complications of diabetes are wide ranging, but can include heart

disease, kidney problems, circulatory issues, blindness, skin issues, depression, and gastrointestinal issues. [1]

There are several categories of diabetes. Type 1 diabetics are those whose bodies have completely stopped making insulin. As a result, they must inject insulin one or more times per day or risk seizures or diabetic coma. Onset of Type 1 diabetes usually occurs during childhood. Type 2 diabetics are those whose bodies still produce insulin; however, the amount of insulin is insufficient or the body cannot efficiently use what is made. The onset of Type 2 diabetes has typically been in the 60+ age range, though the disease is beginning to appear earlier and earlier. Gestational diabetes occurs during pregnancy and mimics the behavior of Type 2 diabetes. Uncontrolled gestational diabetes can be detrimental to the fetus. [1]

Managing and Controlling Diabetes

For all categories of diabetics, the mainstay of treatment revolves around measuring blood sugar levels one or more times a day, and using the results to decide on a course of action or measure control of the disease. Treatment may include insulin injections, oral medications, and/or lifestyle management in the form of low-carbohydrate diets, exercise, etc. [2]

When first diagnosed, most diabetics are assigned to a diabetic counselor. This person helps the patient to determine a custom diet and exercise plan, schedule of blood sugar testing, target blood sugar ranges, insulin doses, etc. The diabetic counselor also takes the lead in teaching the patient about nutritional values of foods, how/what to eat, how to use tracking devices, and how to give injections. Patients are usually requested to keep careful records of their blood sugar levels, insulin, or other medications taken. Additionally they may be asked to keep detailed food and exercise diaries. Patients must send this data to their counselor on a an agreed upon schedule. Without this data, the counselor can only offer general, rather than customized advice.

Unfortunately, keeping such detailed records can be difficult and time-consuming; therefore many diabetic counselors find themselves trying to provide guidance based on incomplete or inaccurate information. Compliance to record keeping and lifestyle management can be especially difficult for Type 2 and Gestational diabetics who may not display any outward symptoms or complications at the present. Many diabetics go through a denial stage where they try to “flexibly negotiate their actions” (i.e. see what they can get away with) rather than adopting 100% risk free behaviors. [2] Additional challenges include staying motivated, avoiding feelings of deprivation, and navigating work, social and family gatherings, or travel situations where food is a prominent component. For most diabetics, the disease must be thought about and managed every single day.

There is also the challenge of logistics. Though some people have very consistent waking, mealtimes, exercise regimes, diets, and sleep times, most people experience at least some change in their schedules and habits from day to day. Simply remembering to eat or take a blood sugar reading at a certain time can be difficult. It's also easy to forget to record foods eaten in a diary immediately following ingestion. It has been shown that later recall of food consumption is unreliable, despite user attempts at accuracy. [3] The patient is faced with the task of figuring out the nutritional value of food to ensure that carbohydrates,

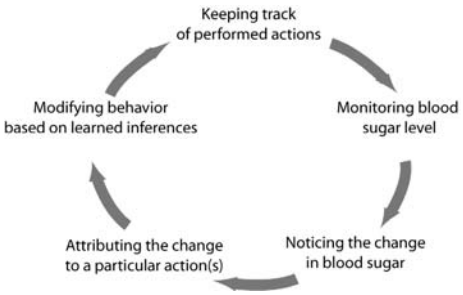

Figure 1: Mamykina et. al found through a series of qualitative studies with diabetics, that success in managing the disease greatly depends on the patients ability to see correlations between their activities and resulting blood sugar levels. This reasoning generally follows a cyclical decision making process. [2]

Since correlating cause and effect is a key goal of the GlucoGo system, this cycle will be used as the conceptual model and structure for describing the different features and how they align to the application's purpose.

proteins, and fats are consumed in appropriate amounts. On top of this, diabetics have the additional burden of relaying this data to their diabetic counselor through means that are often inefficient.

Target Audience

While Type 1 diabetes has been a fairly rare condition, and Type 2 diabetes generally considered a complication of old age; the statistics show some significant shifts in demographics. The ADA estimates that 50% of the 20.8 million diabetics are between the ages of 20 and 60, and about 10% between the ages of 20 and 35. [1] GlucoGo is designed for this younger group who needd diabetic aids that adapt well to their highly mobile and technologically advanced lifestyles.

GlucoGo

GlucoGo is a mobile phone application that will help diabetics track diet and blood sugar readings while learning healthy habits. This includes customized coaching and positive feedback. There are two primary goals with the creation of this application. First is to create a simple all-in-one solution that minimizes the administrative burden of tracking and monitoring the disease. The second goal is to reduce or eliminate the reliance on health-care professionals by providing users with the timely individualized coaching and motivation needed to be successful.

Before users can begin managing their diabetes using GlucoGo, the system will need some information about the individual. Without this, the virtual assistant would be able to offer only generic advice, and track progress against a specific set of guidelines (that may not match the patients' actual program). GlucoGo will collect this information via a wizard that walks users through the process. This necessary information will include things like the type of diabetes, the user's target blood sugar ranges, typical meal times, and preferences for notifications and reminders.

Monitoring Blood Sugar Levels

The GlucoGo system will allow a flexible infrastructure for obtaining blood sugar readings in order to work with the various glucometers commercially available. Users can manually enter readings if they choose, but may also obtain readings automatically from glucometers that send information wirelessly through Bluetooth or infrared technologies. The technology has also recently become available to turn an ordinary mobile phone into a glucometer through an add-on module. [5]

Noticing the Change in Blood Sugar

Users will have control over when and how glucose levels are displayed following testing. New diabetics may want to preview every reading, while experienced diabetics may only want to see a reading that is a certain percentage above or below their target. This choice will be set in the application's preferences.

The meaning of a reported glucose number is meaningless unless placed in the correct context. A reading of 118 may be very high for a fasting level (when the user has fasted for the previous 8-12 hours), moderately high if it has been more than 2 hours since last eating, or just right if it has been only an hour since the last meal. A diabetic using a traditional glucometer must interpret these numbers on their own, possibly referring to a chart when first learning to manage their blood sugar.

Figure 2: GlucoGo reports blood sugar readings in a color format that helps users visualize whether they are on target. Results are shown with green, yellow, or red backgrounds as are charts and other progress indicators. The result above with a green background shows that the reading is within 10% of the target. A yellow border would show a variance between 10-20% and a red one designating a reading more than 20% away from the target.

To reduce the cognitive burden on the user, GlucoGo will attempt to place the reading in the correct context by considering factors such as time of day, the user's stated target ranges, and time of last meal. **[Figure 2]**

GlucoGo users will also be able to pull up graphical charts that show trends in blood sugar readings over time. **[Figure 3]** Users can choose whether to view these graphs manually, or to have the application notify them when an interesting trend is identified. For example, dinner readings for the past five days may have been consistently 20% lower than those for lunch or breakfast. While this could be a good thing, it could also signal a problem. If a user is only seeing individual numbers, however, they will never have the opportunity to reflect on this trend to determine whether some modification should be made. Users of the GlucoGo system will have a third option for viewing blood sugar readings through the use of ambient display technology. An ambient display makes use of changeable mobile phone wallpaper that conveys information about the user's performance against predefined goals. "Visualization of information related to communication can help to increase the user's awareness and hence make it a persuasive technology to push for a certain behavior." [4]

Attributing the Change to a Particular Action(s)

For most diabetics, food has the greatest impact on blood sugar readings. GlucoGo will present a number of options that will ease the logging of food items so that these can be compared side by side with blood sugar readings. This is essentially looking at both cause (food) and effect (blood sugar level). **[Figure 4]**

Two of the most common reasons cited for not keeping a food diary are that users forget and that it is time consuming. [6] GlucoGo will support a number of different methods for capturing food consumed, including scanning of UPC codes on packaged food items (via the phone's built-in camera), snapping a photo of the food, recording a voice memo, looking up the food in an internet food database, or manually entering what was eaten in a text box. These methods allow users to use a combination of methods depending on their current situation. A simple pre-chosen key sequence can put the phone into standby mode, ready to receive a photo, barcode, or voice memo. These quick methods can be used as a reminder to input a more detailed record when the user is less busy or can serve as the record itself when nutritional data or analysis is not needed.

In all cases, users can choose the degree of food tracking appropriate for their lifestyle, severity of diabetic condition, and experience with the disease. Foods entered will receive a time/date stamp and the application will attempt to associate with a particular meal of the day based on user preferences and history. Users can over-ride these time stamps if they forget to make an entry at the appropriate time. With every blood sugar reading reported, users will be able to view the food item(s) eaten in the time periods closest to the reading in question. For some users, a simple reminder of what was eaten will be enough to create understanding of why it caused a problem. In other cases, further explanation might be needed to understand why the food might have been problematic. This will be explored further in the next section.

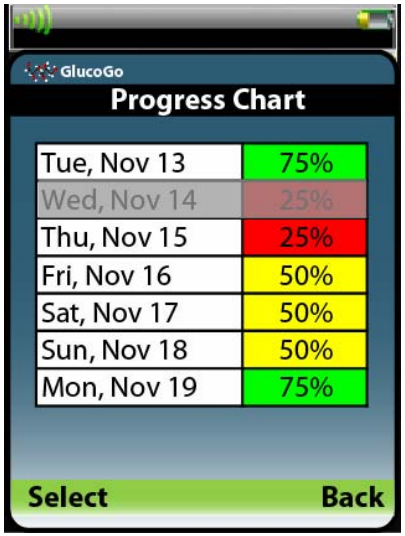

Figure 3: Sample chart that shows adherence to targets for the past week using the green, yellow, red color scheme. Users can select a day (focused in grey) to see that days' targets broken down by meal.

GlucoGo will also offer users the ability to track physical activities and to keep short journal entries each day that may include areas such as mood, amount of sleep, or whether medications were skipped. This allows users to consider other lifestyle factors in the context of their glucose levels.

Modifying Behavior Based on Learned Inferences
In addition to tracking cause and effect, GlucoGo will proactively offer suggestions, analysis, and coaching in a way that is more timely and relevant than what health professionals have typically been able to provide. For example, the software may notice that when lunch is eaten more than an hour late, a negative glucose reading results regardless of what was eaten. In another example, the user may have flagged clam chowder as a problem food last time it was recorded. GlucoGo would prompt the user when clam chowder was again entered so that the user could reflect on whether different ingredients or sources of the soup had any impact on the resulting glucose levels. Such information may be more comprehensive than what a user or health professional would see when reviewing records on their own, and a great deal of time is saved. Simply being told that an issue exists may be enough for users to make mental notes to change behaviors.

GlucoGo would suggest escalation to a health care professional for any issue it could not solve satisfactorily or for trends showing glucose levels that are consistently and/or dangerously high or low.

Keeping Track of Performed Actions
When GlucoGo suggests an action or a user decides on an independent course of action, the user should be able to record the decision that was made. This creates a kind of knowledge base that the user can consult at a later time should the same situation arise again. This is another key factor of the diabetic learning process.

Additionally, users must have the ability to create reports that show patterns and trends over time. Much can be learned from analyzing data over weeks or months that cannot be seen in daily records. GlucoGo users will have the ability to send the corresponding data via email in either PDF or CSV format (for uploading into database applications or Microsoft Excel). This will allow users to share data with health care professionals and other caregivers, or simply to keep a long-term record of progress.

Design Process and Prototype

First, an exhaustive literature review was completed to explore existing research on diabetic disease management, look at the feasibility of using certain technologies in the design (such as barcode scanning), and look at the pros and cons of existing diabetic technologies. This was compiled and submitted as a paper for a class project but is unpublished at this time. It is available by contacting the author. Additionally, several diabetic acquaintances were consulted to discuss needs and issues with managing the disease.

Following this step, personas and use cases were developed. The application was then mapped out on poster-board, using an individual post-it note to represent each unique screen (a low fidelity method of wireframing). This step helped to determine logical flow of the application and also document the interface elements needed at each stage.

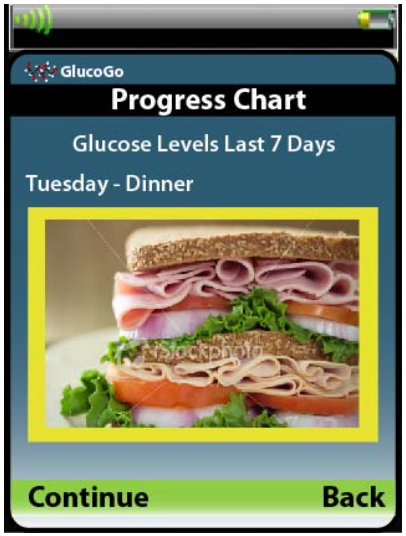

Figure 4: This food diary entry (input via the phone's camera) displays a yellow border which shows the user that this meal resulted in a glucose level 10-20 percent out of range.

Adobe Flash was then used to build an interactive prototype, using the size and interface constraints of a typical flip-style mobile phone. The purpose of the prototype is to test the conceptual model and usage of the application; therefore only 1-2 samples are included for areas like charts, analysis, and database lookups rather than the thousands of options that would be available in a fully developed application. Due to the complexity of this application, it is expected than several more design iterations would be required, as well as a visual design workup.

Flash was chosen as the prototyping method due to Adobe's implementation of Flash Lite on many brands of mobile phones. Flash Lite allows applications to be created and deployed to a phone using Flash, rather than more programming intensive development environments such as Java. This requires some additional coding in Actionscript, but is still easier overall than coding from scratch. Additionally, Flash Lite applications can run in Adobe's Device Central mobile simulators, so that users and developers can experience and test the interface in the context of a real phone. Some of the important questions for a user evaluation session have to do with the feasibility of navigating and using a data intensive application on a small screen. A test environment that most closely approximates conditions will be better for answering these questions and determining next steps.

Future Work

The next steps involve qualitative user testing of the prototype with a variety of diabetics of various demographics, but with a focus on the younger adults and heavy mobile phone users. If the first round of user studies show promise for the application and validate the conceptual model, some engineering resources will be needed for the next phase. One of the biggest challenges going forward will be writing the algorithms to handle the huge numbers of variables required for making this a truly smart application, and getting large amounts of data to work with a small memory and storage footprint. Such challenges are beyond the scope of this work, however, whose goal was to simply identify a need and design a solution to address it.

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