Diabetes Management using Smart Health Devices, Personal Health Informatics, and Community-Sourced Support

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Abstract: Diabetes is a chronic illness without a cure, requiring continuous medical care with management strategies beyond glycemic control to delay if not prevent, acute complications that result from poor diabetes management. Disease management is an approach to healthcare that teaches patients how to self-manage a chronic disease (Torrey, 2019). Diabetes self-management education training has shown to improve glucose control and thus may reduce long-term complications such as retinopathy, neuropathy, and cardiovascular complications. In self-management, patients face a variety of issues from difficulty in daily self-monitoring and manually recording health information to difficulties in tracking and analyzing health records for decision making. DiaBeatIS is a mobile application for diabetes management using smart devices, personal health informatics, and community sourced reviews as support to diabetic patients. The application was designed following the Stage-Based Model introduced by (Li, 2010) that defines the different stages users go through from self-understanding to taking actions, which serves as a guide in developing effective personal informatics systems. Aside from personal informatics, key design innovations introduced in the development of the application included (a) Smart Device Integration (b) Integration from Information Services (c) Location-based information about pharmacies and restaurants.

Key Words: Personal Informatics, Personal Health Informatics, Diabetes

1. INTRODUCTION

Noncommunicable diseases (NCDs), including heart disease, stroke, cancer, diabetes, and chronic lung disease, are collectively responsible for almost 70% of all deaths worldwide (WHO, 2017). Diabetes is a complex, chronic illness requiring continuous medical care with multifactorial risk-reduction strategies beyond glycemic control. This management of the disease is aligned to the World Health Organization's Sustainable Development Goal target 3.4, which is to reduce by one-third premature mortality from noncommunicable diseases through prevention and treatment, and promotion of mental health and well-being by 2030. In line with this, the United Nations calls for global action to halt the rise and improve care for people to beat diabetes (United Nations, 2016).

Disease management is an approach to healthcare that teaches patients how to self-manage a chronic disease (Torrey, 2019). Diabetes self-management education training has shown to improve glucose control and thus may reduce long-term complications such as retinopathy, neuropathy, and cardiovascular complications. Personal and health informatics application is one solution to support patient self-management education through the collection, integration, and presentation of patient's health, activity, and medication information, in each person's everyday battle of the disease. Such applications provide the necessary steps and proper knowledge to halt the progress of diabetes, ultimately improving health outcomes.

Patients face the following difficulties in diabetes management:

(1) *Planning:* difficulty in daily self-monitoring and manually recording health information;
(2) *Organizing:* difficulty in organizing information shared by diabetic communities;
(3) *Controlling:* difficulty in self-maintenance including food effects on blood glucose level, locating restaurants available nearby offering diabetic-friendly menu, and locating pharmacies stocked with medications for diabetes;
(4) *Tracking:* difficulties tracking and analyzing health records for decision making.

One of the factors that contribute to the abandonment of personal informatics applications is the perceived "hassle" (Epstein et al., 2016) brought about by manual collection of data. In this study, smart devices were introduced and integrated into the application to allow data collection (e.g. blood glucose, activity, and sleep) without the need for manual data collection. Location data such as where medicines were bought and where restaurants patients ate are located were likewise automatically collected using built-in GPS on mobile devices. Other data that needs to be collected for diabetes management remained to be done manually.

With the prevalence of smartphones, it is now possible to use mobile technology and applications to empower patients to better manage their diabetes. This study builds on this opportunity and the growing need to develop tools to help patients self-manage their diabetes by developing a mobile personal health informatics application named ***DiaBeatIS.*** The DiaBeatIS project is composed of two major components - the Personal Informatics Mobile Application and the Clinical Informatics Web Application. This paper focuses on the Personal Informatics mobile application of the project.

2. METHODOLOGY

The development of DiaBeatIS adopted the Agile method of software development, specifically Scrum. Scrum was chosen because of its three pillars that uphold every implementation of process control namely (1) transparency, (2) inspection, and (3) adaptation. The project also used the idea of "Sprints" which are "short, time-boxed period the development team works to complete a set amount of work" (Gurendo, 2015). For the project, the following phases were done for each sprint:

1. Product Backlog Creation
2. Sprint Planning
3. Working on the Sprint
4. Testing and Product Demonstration
5. Retrospective and Next Sprint Planning

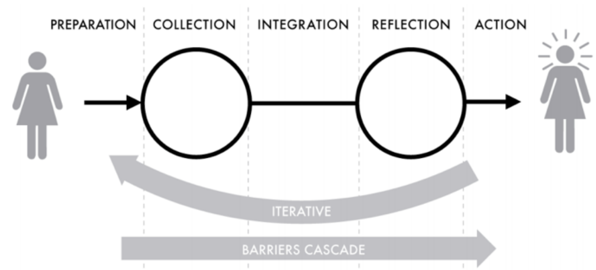
A Trello board was used as a project management tool to keep track of progress.

3. DESIGN HIGHLIGHTS

The Stage-Based Model was introduced by (Li, 2010) to define the different stages users go through that will guide developing effective personal informatics systems. The model has five (5) stages as shown in figure 3.1. These stages are (a) Preparation (b) Collection (c) Integration (d) Reflection and (e) Action.

The model has four (4) properties but only the property of (a) Stages are iterative (b) Stages are user and/or system driven were considered for the development of DiaBeatIS. The properties of (c) barriers in the stage cascades and (d) stages being uni-faceted or multi-faceted were not considered in the design of the application.

Figure 3.1 Stage-Based Model for Personal Informatics



3.1 Preparation Stage

The preparation stage was implemented by having a "Defining Self" and "Defining Goals" modules. The definition of "self" involves the registration of data about the user that are important to the functionality of the personal informatics application (including data collection). These information included (a) user's birthday (b) type of Diabetes (c) current active lifestyle (d) existing complications from Diabetes (f) current height and weight and (g) existing allergies. Information about the user's goal as part of self-management of diabetes included (a) target weight and target date to achieve the goal (b) nutritional target in calories and nutritional components (c) blood glucose maintenance goal (d) and medication information. The information collected from users during this stage determines not only the data to be collected but also how the data will be shown to induce reflection.

As part of supporting the patients activities involving (a) looking for restaurants and menus, and (b) pharmacies, DiaBeatIS introduces the idea of community-sourced information from people (or peers) who have the same diabetes condition and complications for an improved access to targeted, directed and relevant peer-contributed information. To determine the relevant and targeted information, some of the information about the "self" were used. A virtual community of diabetic peers with the same condition and complications is created within the application.

3.2 Collection Stage

The collection stage refers to the users' collection of data about themselves (Li, 2010). In DiaBeatIS, data collection was implemented in both device-collected and manual data collection modes. The user and/or system driven property of the stage-based model is best shown during this stage. There are data that the user has absolute control of its collection, and there are data designed to be in control of the devices.

3.2.1 Device-Collected Data using Smart Device Integration

Smart Device integration was implemented to reduce the amount of manual data collection. The smart devices the application was designed to work are FitBit and iHealth Glucometer. These smart devices are selected because of the availability of APIs that will enable data integration with the application. Fitbit is a device that collected data about the user's heart rate, quality of sleep and the number of steps walked. iHealth Glucometer is a device that collected data about the user's blood glucose levels. The smart devices collects personal data and synchronizes (using Bluetooth technology) these data to their respective proprietary application that is installed in the user's mobile phone. These proprietary applications are programmed to synchronize their data to a cloud server that offers API for data integration with DiaBeatIS.

Although iHealth API can integrate data collected from its family of smart devices (such as weighing scales and blood pressure monitors), the limited budget for the project prioritized and selected iHealth glucometer and its data on blood glucose to be integrated in DiaBeatIS.

3.2.2 Manual Data Collection

Manual collection of data implemented either the following modes (a) selection of pre-codified data choices and (b) manually entering actual data values. Table 3.1 shows the categories of personal data and the data collection mode used for its collection.

Table 3.1 Personal Data and Manual Collection Mode

Personal Data	Data Collection Mode
(1) Medication Intake	Codified Choices Manual Entry for overriding codified entries
(2) Nutrition	Manual Entry
(3) Body Measurements	Manual Entry

Medication intake uses codified choice selection and in-situ data (actual date and time the user indicated taking the medication as recorded by the mobile phone), but considered providing the ability of users to manually override data entry. As much as in-situ collection provides representation of data as it happens, users often perform data collection in post-situ. Nutrition data includes data collection on food intake. To reduce data collection, the application introduced the integration with Nutritionix, a search engine and database for nutrition information. Using data about the food taken, integration with Nutritionix allows the application to automatically retrieve the nearest nutritional components of the food taken rather than to have these data manually collected from users.

3.3 Integration Stage

The Stage-based Model of (Li, 2010) defines the reflection stage as where the data collected are prepared, combined and transformed for user reflection. Data processes in this stage is categorized into (a) Descriptive Statistics (b) Percentage Completion Calculation (c) Predictive Calculation.

Descriptive statistics on total and average are computed as needed when presenting summarized information to users. For health data concerning defined goals, progress represented by percentage completion is being computed.

One of the important design highlights of this study is the attempt to do conversion of caloric intake and activity data into glucose increase or decrease. Historical data on caloric intake against the increase in blood glucose level as well as activity data against the increase in blood glucose levels were used to develop a ***linear regression*** model that will predict the resulting glucose increase (good intake) and glucose decrease (activity). This conversion is used and presented to users to induce reflection and allow them to decide whether to reduce intake or perform activities to achieve their target blood glucose range.

3.4 Reflection Stage

Reflection is induced through the health dashboard of the application. The dashboard contains information presented both raw and visual forms. Target Data from preparation stage, Data collected from the collection stage and processed data from the integration stage are combined in the dashboard to provide users with

a. State of the Health (Current and latest data collected about the user's health)
b. State of Health against Target (Comparison of health data to defined target)
c. Historical data of Health (Progress). Progress can be viewed in either a daily, monthly or yearly perspectives.

3.5 Action Stage and the Iterative property of the Stages

(Li, 2010) described the action stage as the stage where users decide on what they are going to do after reflecting on the information about themselves and their progress towards goals. DiaBeatIS is not designed to introduce possible actions to take from what the application may have been understanding about the user's health. The application left the determination of actions to take with the users. Every action decided by the user will in turn become additional personal health data (such as food intake, heart rate, activity, sleep, blood pressure, among others) and after some time may trigger the adjustment of goals and data about self (e.g. weight). This is part of the iterative property of the stages in the stage-based model. Even if the stages are performed in iterations in DiaBeatIS, it is not able to implement what the stage-model further described the iterative property as:

a. supporting importing data from other and new systems
b. exporting to other systems
c. supporting different kinds of information as users identifies its need for its own understanding of self

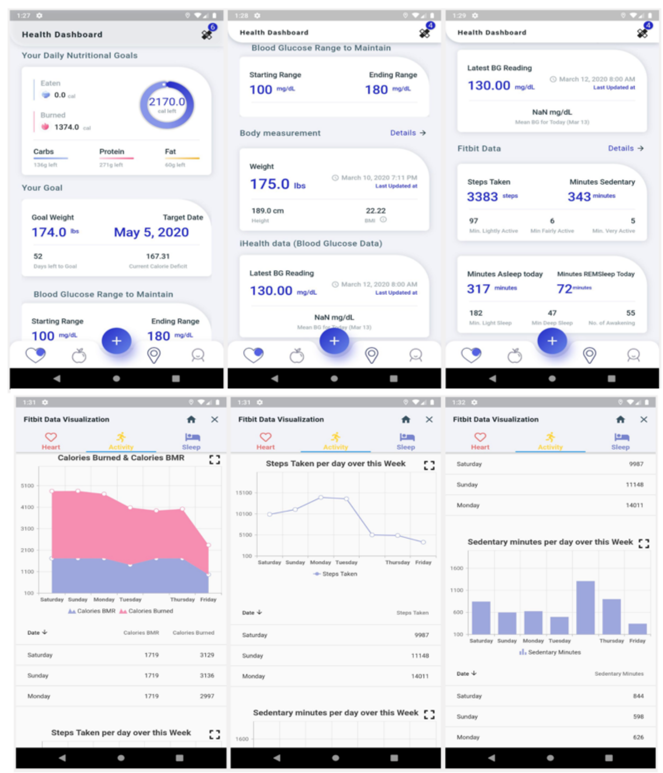


Figure 3.0 Some screenshots of the mobile application

3.5 Other Design Highlights

Other design highlights in the development of DiaBeatIS includes:

a. Integration of Authentication Services
b. Data Privacy Notice
c. Design of Crowdsourced Reviews on Pharmacies and Restaurants based on Location

4. RESULTS AND DISCUSSION

The mobile application went through a two-stage test: (a) Unit Testing (b) User Acceptance Testing (UAT). Unit testing was conducted to ensure that functions for the key application areas are executed Each test case contains test steps, test data, precondition, postcondition developed for specific test scenarios to verify any requirement. The test case includes specific variables or conditions, using which comparison between expected and actual results could be made to determine whether the application is functioning as per the requirements. Table 4.1 shows the different test areas and the number of cases used to test each functional area. The users used the application for approximately 4 hours under supervision of the researchers. During this period the users expressed huge interest as to when the project will go live because they see the utility, and value in the application. Convenient Sampling of users with age range of 20-76, have diabetes with varying complications with the heart, and kidney.

Table 4.1 Unit Test Areas and Test Cases

Unit Test Areas	No. of Cases	Test Result
(a) Defining Self and (b) Goals	15	OK
(c) Smart Device Integration and Device Data Collection	5	OK
(d) Crowdsourcing information based on Location	10	OK
(e) Nutrition Data Collection	13	OK
(f) Medication Data Collection	6	OK
(g) Weight Data Collection	6	OK
(h) Viewing the Self	9	OK

While the application was designed primarily for the needs of the patients, subsets of the features of the application were made available for the use of caretakers as part of supporting the patients. Given this, both users were administered the UAT questionnaire.

Due to time constraints to complete the project and perform user acceptance testing, convenient sampling was used, with five (5) patients and five (5) caretakers. Qualitative data was not gathered during the user acceptance testing. During the test, the application was demonstrated to the users, and users were given the opportunity to use each function. Users were administered a questionnaire with eight (8) criteria on user satisfaction. A Likert scale was provided for users to rate each from being very dissatisfied - VD (1.000) to very satisfied - VS (5.000).

Table 4.2 UAT Results for Patient and Caretaker

Criteria	Patient	Caretaker
(1) Effectiveness of Specific Function to the User	4.076	4.502
(2) Smart Device Integration	5.000	4.600
(3) Visualization	4.800	5.000
(4) General Application Convenience	3.800	4.200
(5) General Application Effectiveness	4.600	4.600
(6) User Experience at First Use	3.600	4.200
(7) The Relevance of Functionality to User	4.600	4.200
(8) Likelihood of Recommending the Application	4.200	4.200
Average Satisfaction Rate	**4.334**	**4.438**

4.1 Data Collection, Visualization, and Abandonment in Personal Informatics

Patients showed high satisfaction on several criteria including the (1) effectiveness of functions for patients, (2) smart device integration, (3) visualization, (5) the general effectiveness of the application, (7) relevance of functionality to the user, and the (8) likelihood of recommending the application. Epstein et al. (2016) show that users are likely to abandon personal health informatics applications when they perceive data collection as a "hassle", because of the regular manual entry. Additionally, their results showed that people desire greater accuracy of data, and this accuracy can be best presented to users through data visualizations.

It is important to note that both patients and caregivers demonstrated high satisfaction with the application's visualization and smart device integration functions. This high satisfaction results in this study on smart device integration and data visualization may reduce the likelihood that the DiaBeatIS application will be abandoned.

4.2 Convenience and User Experience in Applications

Convenience is an element of customer experience associated with time and effort in performing something. The same definition is used in the work of (Jiang, 2013) and (Khrais, 2017) on convenience in banking and online shopping systems. User Convenience is a perception arising from the user's experience of the system (including the application used within the system). This puts user experience as a component that influences convenience. The results of the UAT showed consistency to this relationship and can be interpreted that the user experience on the app affected the overall perception of convenience. This study is not able to identify and collect data about the elements of the application design that affected user experience.

5. CONCLUSIONS

DiaBeatIS is a personal health informatics application that supports the self-management of diabetes. As a personal informatics application, it was designed following the stage-based model proposed by (Li, 2010). To address the difficulties experienced by diabetic patients, aside from personal informatics, key design innovations introduced in the development of the application included (a) Smart Device Integration (b) Integration from Information Services (c) Location-Based Information for Pharmacies and Restaurants. Results from the User Acceptance Test reveals an overall average satisfaction score of 4.334 and 4.438 from patients and caretakers respectively, in eight criteria. The result shows there is value in the use of the application for self-management of the disease using personal data. The study recommends that future work in personal health informatics consider the collection and analysis of data concerning user experience design and how it affects user convenience. It is also recommended that an in-depth study at the other factors affecting abandonment of personal health informatics applications and what application design can be introduced to further reduce abandonment.

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