DiaMeter: a Mobile Application and Web Service for Monitoring Diabetes Mellitus

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***Abstract* — Diabetes mellitus currently is a very common disease that affects a growing number of people every year. The most difficult problem for the patient is the disease monitoring, which requires a regular diabetes diary management, insulin dosage calculation and adjustment. The usage of mobile applications can significantly help patients to track their condition, control the disease and improve their health. This paper covers the development of DiaMeter: a mobile application and web service for people with diabetes. It provides the user with the ability to conveniently monitor and manage his or her medical data, calculate insulin doses, review the blood sugar statistics, create reminders and manage food ration. We provide an analysis of system requirements, review the existing solutions in the area of mobile medicine, design the architecture of client and server parts of the application, review the development of the application interface and review the results of the service implementation.**

Keywords— diabetes mellitus, mHealth, mobile, healthcare, big data, application, patient monitoring, blood glucose.

I. Introduction

According to [1], the prevalence of diabetes mellitus in Russia as of December 31, 2017 reached 4,498,000 patients (about 3% of the Russian population). Based on these data we can observe a significant growth of diabetes prevalence in Russia: in comparison with the data from January 1, 2015 the number of people with diabetes has increased by 404,000 patients within a two-year period (9.8%) [2].

Self-control and correction of the disease is the most significant task for a patient with diabetes mellitus. Consistent monitoring of diabetes by the patient, in the form of a paper diary, is rarely achieved by patients due to the inconvenience and complexity of the process itself. At the same time, the lack of competence of the patient and low amount of data limits the possibility of the disease management.

We have developed a mobile application and a web service to provide collection of the patient's medical data for the diabetes diary management. This data can be used for further analysis both by the patient and by the endocrinologist.

II. Subject Area and Related Works

A. Mobile Health

The use of mobile applications and mobile devices can help patients to track their condition and control the disease. The appearance of mobile devices capable of solving complex tasks has led to the development of mobile technologies in the field of medicine and health care. Recently there has been a lot of research in the field of Mobile Health (mHealth) [3], which studies the ways of using mobile technologies for the monitoring and treatment of patients.

There are multiple ways of using mobile medical technology, and in recent years large corporations have also been working on research and solutions to health issues.

In 2018, Apple released a new version of the Apple Watch Series 4, which focuses on monitoring users' health. The new version provides ECG readings that allow the wearer to detect abnormalities in their heart in the early stages. The watch also allows you to visually monitor your activity, motivating people to be active. At the same time, the watch does not ignore the mental health - it reminds people to take a break and give a minute for breathing exercises to lessen unnecessary stress.

All these small functions allow us to understand the state of human health better. Authors of [4] showed that the data from Apple Watch is useful in assessing the state of the heart, the data that these devices record should be taken into account and cannot be ignored. Additionally, data from portable devices should be considered as important information for health-related decision-making by all involved parties, including patients, family members, health care providers, public health professionals and politicians [5].

B. Mobile applications for patients with diabetes mellitus

In a study where patients with diabetes were given the opportunity to use a mobile application to control their disease, most people reported a positive change over the course of the study (86.7%) and the convenience of the disease management application (96.7%). Almost all participants (97.7%) reported that they actively recommend other people to use the app, and 96.7% reported that they will continue to use the app [6].

There are a lot of mobile applications available for people with diabetes, but many of them do not have the necessary functionality [7]. According to [8], personalized support and decision support are not integrated into most current developments, despite their need.

Based on the analysis of mobile applications in the AppStore the need of applications for diabetes management is present both around the world and in Russia. At the same time, the main tasks that these applications solve are diabetes diary maintenance, analysis of sugar levels, the monitoring of the amount of consumed carbohydrates and assistance in the calculation of the necessary insulin dose. The main factors that users pay attention to when choosing an application are the speed and convenience of data entry, design, reliability of the data provided by the application, available features in the free version of the application and the cost of the paid version.

C. Wearable devices for patients with diabetes

Collection and analysis of diabetes data can be a time-consuming process for individuals. To solve this problem, there are devices that can automatically record and synchronize data such as blood sugar levels.

These devices can be divided into three groups:

- Glucometers, with the ability to synchronize data with a mobile phone;

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- Continuous blood sugar monitoring systems with the display of the information on the device itself, allowing to save the data on a computer;
- Continuous blood sugar monitoring systems with the ability to access this data via an NFC chip in the device itself with a mobile phone.

The study [9] has shown, that these systems can significantly improve the process of collecting data about users' sugar levels. This can improve the quality of patient's diabetes management and result in a more stable blood sugar level. This is confirmed by the fact that the average sugar level in the patients participating in the study has become closer to the target level than before the start of the study.

The main disadvantage of the use of these technologies is their cost. Because of the need for frequent use of the tools for monitoring blood sugar levels in patients with diabetes, the total cost of consumables per month may increase by 2-4 times in the result of using these new technologies. Because of this, the ability to quickly, cheaply and conveniently monitor blood glucose levels is still important for many diabetics.

D. Related mobile applications

Although there are many services for diabetes management available on English language, the applications with Russian language are much less frequent.

A lot of the apps found by the keyword “диабет” (diabetes in English) in Russian AppStore are focused on tracking daily nutrition, without ability to monitor diabetes related parameters. Not considering “Diameter”, the most popular applications focused on diabetes monitoring are “Диабет” (“Diabetes“ in English), “диабет+” (“diabetes+“ in English) and “MedM Диабет” (“MedM Diabetes“ in English).

Besides the interface design main disadvantages of those applications comparing to DiaMeter are:

1) small or absent food database;
2) limited or absent insulin dosage calculation;
3) absent or difficult to read sugar, insulin and carbohydrates statistics;
4) absense of learning theoretical material;
5) limited reminders functionality;

But features of Diameter application are limited if we compare it to most popular applications available on the English language. The main goal of the development right now is to add more helpful and important features to the application, including blood sugar prediction, physical activity and condition tracking and ability to share data with relatives and physicians.

III. Application use cases

The DiaMeter system includes a mobile application and a web service that provide the user with the ability to manage their medical records and with advanced features for more convenient disease control. With DiaMeter, the user can manage their medical records and their diet. The application will provide the user with statistics of their sugar levels to visually monitor the trend of the disease based on the entered data.

The "Patient" actor can implement the following use cases with the DiaMeter system (see Fig. 1):

1) The patient can add and modify medical values in the mobile application by using a convenient format for entering the data. This data includes: date and time of the record, blood sugar level, amount of bread units eaten, meal, amount of prolonged and short insulin units.

2) Patient can manage the nutrition in a diary with medical indicators.

3) The patient can add new foods nutrition into the public database of the web service.

4) The patient can set up reminders to keep track of the disease in order to remember procedures such as measuring blood sugar levels, eating or injecting insulin.

5) The patient can calculate the recommended insulin dose based on current blood sugar levels and the amount of carbohydrates taken, if insulin sensitivity ratio and carbohydrate ratio are specified in the preferences

6) The patient can manage physiological parameters and change the following dynamic variables: *weight, height, insulin sensitivity and carbohydrate ratio, presence of insulin pump, set of of insulin types;*

7) Patient can view all available medical data in one of the provided formats (table, diagram).

8) The patient can take a test to check the theoretical knowledge of diabetes management.

9) The patient can manage settings that include the following static parameters associated with the account: *gender, birth date, diabetes type.*

10) Users can also change the settings that are responsible for the user's interaction with the application in their usual units of measurement, such as the following: *the number of carbohydrates in one Bread Unit, blood sugar measurement unit, target, low and high sugar levels.*

11) Patient can read educational materials about monitoring and management of diabetes.

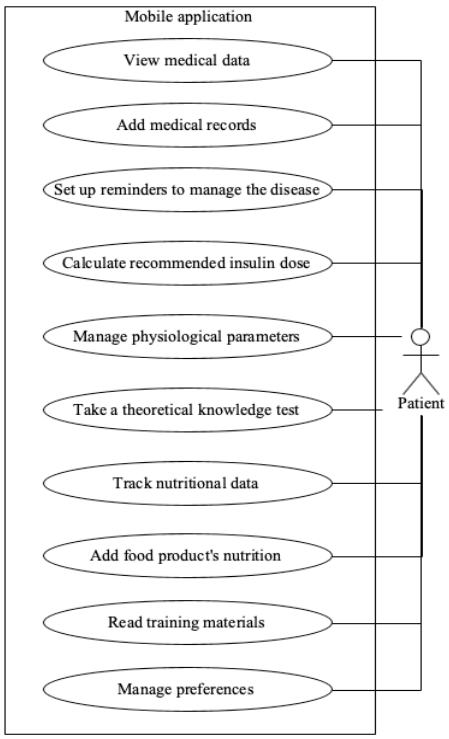

Fig. 1. DiaMeter mobile application use cases

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IV. Web-service architecture

In order to store and synchronize data between user devices and to provide further access to this data to endocrinologist and relatives, a web service was developed.

We have developed a database schema that contains information about system users, all diabetes journal entries, all products in the system, product categories, units and available images for units. A total of 17 tables have been developed, but here we will look at 3 tables (see Fig. 2) responsible for the storage of user's diabetes diary data.

1) Record - a table with medical therapy data in the diabetes diary, it contains data on the time of recording, blood sugar level, the amount of injected bolus and basal insulin and the food in the meal.

2) ProductRecord - a table for linking food available in the web service and diabetes diary records. This table also stores data on the amount of carbohydrates and the portion of the product at the time of the record to ensure that the data in the diabetes diary are consistent in case if the user makes future adjustments to the nutritional value of the product.

3) Product - a table for storing information about food items available in a web-service. It contains information about the name, type of measurement unit, amount of carbohydrates, proteins, fats and kilocalories, glycemic index of the product, standard weight of the portion, category of the product, author of the product, whether the product is public or private and whether the product is moderated for publication and whether the entered data are correct.

V. Development of the mobile application interface

A. Diary screen

The diary screen is the application's main screen that appears when the user opens the application (see Fig. 3a). From this screen the user can immediately add a new record and, to save time, he can go straight to the entry of the necessary value of the record, skipping the previous ones. In addition to the input screen, the last 10 entries entered by the user and future notifications are displayed on the diary screen so that the user can easily see his recent and planned activity.

On the input screen the user spends most of his time in the application. This is confirmed by the analysis of user behavior through Fabric Answers anonymous analytics service. In order to provide efficient work with this screen, we had to solve the task of reducing the necessary time for data input.

All the most popular mobile applications now use a system of data input using the keyboard or a picker. Since the input values are mainly semicolon numbers and there are 4 types of such values (plus the comment), the standard options will require a lot of time for the user to enter them. In case of a keyboard option, these are the delays associated with the animation of opening and closing the keyboard, the transition between the value fields and the direct entry of numbers, where semicolon complicates the process. In the case of picker there is a problem that the value range is very large, and the step is only 1/10, so the user will have to scroll the picker for a long time.

Realizing that standard components for fast data input will not work, we developed our own variant of value input, consisting of two sliders, where the upper slider is responsible for the whole part of the number and the lower one - for the decimal. Thus, the user only needs two clicks on the screen to enter data, and in case of an error, he only needs to move his finger slightly. At the same time, if somebody finds this method unusual or incomprehensible, we have left the possibility to enter data not only with the help of sliders, but also using the standard keyboard. Both methods work together and by entering data using the keyboard, he can, for example, correct an entire portion of the number with the slider.

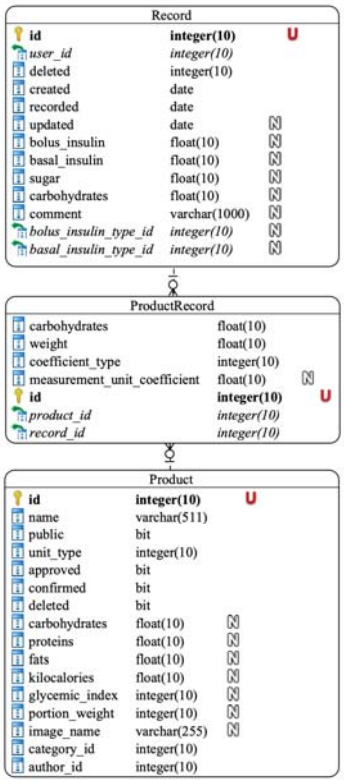

Fig. 2. Diabetes diary storage on the web service

Also, in a number of the reviewed apps for diabetes diary, while entering data the user is either provided with a large table, where he needs to fill in all the data one by one using the keyboard, or provide a step-by-step process of filling, where he needs to move between the steps back and forth. In our case, we decided to combine the two options and saved the user the opportunity to move to any step of data entry, without overloading the user with unnecessary information. Also, the appearance of the input sections allows the user to see which data are already filled in. Another important function implemented in this screen is the function of insulin dose calculation, which allows the user to specify the insulin dose to be entered with one click, which is calculated based on the level of sugar or eaten carbohydrates entered by the user, as well as the entered ratios.

B. Targets screen

Analysis of user activity revealed the problem of user tiredness from using the application. To increase the motivation of users to manage diabetes journal entries, we decided to use the reminders mechanism. To manage the reminders, we have implemented the targets screen (see Fig. 3b). This screen allows the user to create reminders about sugar measurements, meals or injections of insulin, and the targets can be configured so that they are repeated every day (for example, to remind about meals and injections of basal insulin). With automatic target creation, the user can set up a scenario where the application will remind him to measure sugar 1.5 hours after eating and injecting insulin. The

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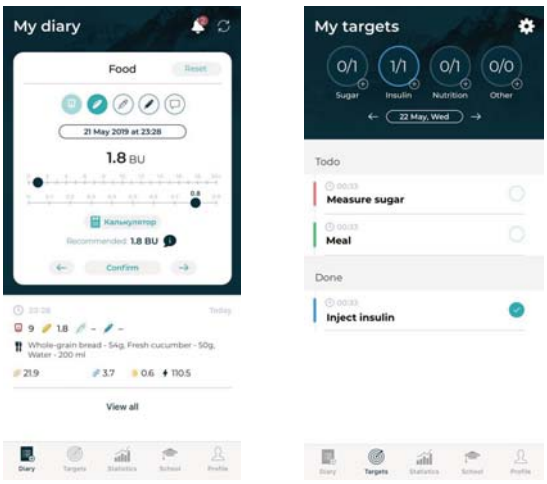
application can also mark the target completed, if the user enters the record which contains the value coinciding with type of the target.



(a) Diary (b) Targets

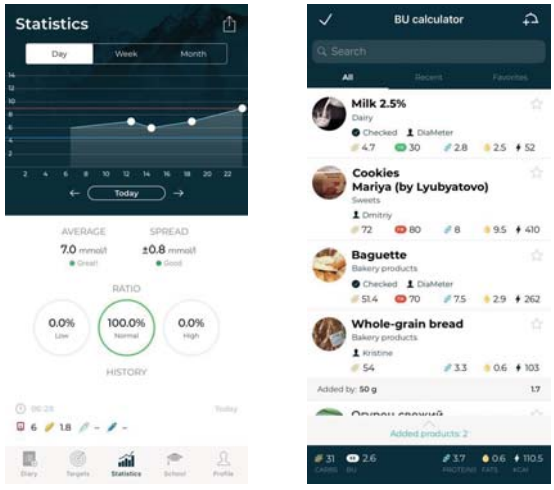
Fig. 3. Statistics and Carbohydrate calculator screens

C. *Statistics screen*

All entered data should be shown as clearly and visually as possible, in order to allow the user to analyze them in the future. Thus, the statistics screen (see Fig. 4a) displays information about the most important indicators that a person with diabetes needs, such as the dynamics of sugars, average sugar, the variety of sugars and their balance. By applying a solution in which the chart goes from one edge of the screen to the other, we have created a sense of connectedness of charts. If the user needs to look at exact record, it can be done simply by pressing a point on the chart.

D. *Carrbohydrate calculator screen*

Carbohydrate calculator screen (Fig. 4b) has been developed to make it easier for the user to count carbohydrates in the meal. The screen provides the user with a list of products and allows to filter it by favorites, recently used and ones, containing the search string. All data are loaded automatically from the web service. All users of the application can send new product's nutrition for moderation into the public database of products. This way, the number of available products in the application increases thanks to the efforts of all application users.



(a) Statistics (b) Carbohydrate calculator

Fig. 4. Diary and Targets screens

CONCLUSION

The DiaMeter application was released two years ago and during this time 30 800 people have already registered in it, which together added 1 400 000 diabetes diary records. Based on an anonymous sugar analysis of 300 randomly selected users with average sugar above 9 mmol/l within a month from the beginning of using the application, we were able to determine that after using the application for more than two months their average sugar decreased by 0.83 mmol/l, and the spread of sugar decreased by 0.33 mmol/l.

Based on the system developed in this work, another study was conducted on the impact of keeping a DiaMeter diabetes diary on the course of type 1 diabetes in children and adolescents [10], the results of which show that keeping a DiaMeter self-control diary has a positive effect on the level of self-control in all age periods, with the best results in the age group of 6-14 years. The study also shows that the DiaMeter application has a positive effect and not only improves the course of the disease but also helps motivate children to self-control diabetes. The development of such systems may not only help to improve the patient's condition, but also to build a properly labeled database with data on diabetes that can be used for machine learning.

In the future, we plan to find ways of processing gathered data in order to present users and their physicians valuable information about their disease, add new types of input data to the application and introduce intelligent analysis of the patient's diabetes state and develop an algorithm for predicting blood sugar levels based on irregularly distributed data.

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