The System of Automated Diabetes Control

Vitalii L. Levkivskyi[1][a], Galyna V. Marchuk[1][b], Oleksandr V. Kuzmenko[1][c] and Anton Yu. Levchenko [2][d]

[1]*Zhytomyr Polytechnic State University, Department of Computer Science, 103 Chudnivska Str., Zhytomyr, 10003, Ukraine*
[2]*Zhytomyr Polytechnic State University, Department of Software Engineering, 103 Chudnivska Str., Zhytomyr, 10003,*

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Abstract: Modern information technology creates new opportunities for quickly obtaining information about the status and trends of diseases such as diabetes. This paper considers the task of automating the collection and analysis of data on the condition of a patient. The object of the research is information technology for creating mobile applications and mathematical models for calculating the optimal insulin therapy. The aim of the work is to analyze the incidence of diabetes and the development of a software product for man-aging blood glucose levels. We developed a self-control diary which is the main functional feature of the system. It allows users to quickly obtain in-formation about the state and trends of the disease. Based on the accumulated daily data, it is possible to take the necessary actions on time to improve the disease course. In the process of development, the database was designed and mathematical methods were used to analyze the data. The module of the analysis of the collected data for the specific period is developed. The results of the analysis can be obtained by the following indicators: the average glucose blood level, the number of glucose measurements, glucose deviations, the number of basal insulin injections, the number of hypo/hyperglycemia, the amount of bolus insulin. In our work we used object-oriented design techniques, document-oriented databases, modern web technology stacks for mobile application development and design of interfaces. The result of solving the given task is a system of accumulation and systematization of statistical data on the course of the disease. An automated diabetes control system has been designed and developed. Mathematical models were used to calculate the glucose/insulin balance. The developed software can significantly improve the living standards of people with this disease. The system was tested by patients with diabetes.

1 INTRODUCTION

Diabetes mellitus, commonly known as diabetes, is a chronic disease characterized by high blood glucose level over a prolonged period of time. This leads to serious problems in various systems of the human body, especially nerve endings and blood vessels. Diabetes is a dangerous complication that leads to disability. In low- and middle-income countries, the prevalence of diabetes is growing faster than in high-income countries.

Diabetes is one of the leading causes of blindness, kidney failure, heart attacks, strokes and lower extremity amputations. From 2000 to 2016, premature mortality from diabetes increased by 5%. In 2019, diabetes be-came the ninth leading cause of death in the world and is estimated to be the direct cause of 1.5 million deaths. According to the World Health Organization (WHO), the disease increases mortality by 2-3 times and significantly reduces life expectancy. At the same time, the number of patients increases annually in all countries by 5-7%, and doubles every 12-15 years (World Health Organization, 2022).

Diabetes is treatable. A healthy diet, regular physical activity, maintaining a healthy weight and abstaining from tobacco use can prevent or delay the onset of diabetes. The implementation of the mobile application "Automated Diabetes Control System" will allow for more effective treatment, thereby improving the course of the disease. Users will be able to keep a diary of self-control, particularly to enter and edit data of physical activity, taking medication and food; view disease-based analytics based on input and sync

[a] https://orcid.org/0000-0002-1643-0895
[b] https://orcid.org/0000-0003-2954-1057
[c] https://orcid.org/0000-0002-4937-3284
[d] https://orcid.org/0000-0002-4411-6465

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data with an application server.

2 PROBLEM STATEMENT

Diabetes is a disease whose main symptom is a constant rise of blood sugar level. In the human body, the pancreas is responsible for stabilizing blood glucose levels, producing the hormones insulin and glucagon, which in-crease or decrease glucose levels. However, patients with diabetes have pancreas malfunction in combination with low insulin sensitivity. This leads to fluctuations in blood glucose levels, in particular to the appearance of both hyperglycemia (high glucose concentration) and hypoglycemia (low glucose concentration). Therefore, there is a need to find treatments that can improve the living standards of people with this disease.

The main purpose of our research is to analyze the problem of diabetes and to develop an automated control system. The defined purpose determines the following tasks:

- to define the basic metrics and ways of their reception for the development of the mathematical module of the system;
- to design the structural components and algorithms of the system;
- to develop an automated disease control application.

3 REVIEW OF THE LITERATURE

The article "Global and regional diabetes prevalence estimates for 2019 and projections for 2030 and 2045: results from the International Diabetes Federation Diabetes Atlas, 9th edition" evaluates the prevalence of diabetes in 2019 and forecasts for 2030 and 2045. The study was conducted on 255 qualitative data sources from 138 countries. Data was taken from adults aged 20-79 years for the period from 1990 to 2018, the forecasts are not comforting (Saeedi et al., 2019). According to the IDF diabetes Atlas, the global prevalence of diabetes in 2021 is estimated at 10.5% (536.6 million people) and may increase to 12.2% (783.2 million people) in 2045 (Sun et al., 2022).

Saeedi et al. (Saeedi et al., 2020) estimated the number of deaths related to diabetes among adults aged 20–79. Diabetes is estimated to cause 11.3% of deaths worldwide. Using a model that has only one glucose compartment in its structure, the authors conducted a number of simulations: taking into account the peculiarities of glucose absorption from the intestine, they improved the procedure for detecting latent forms of diabetes and analyzed the optimal insulin therapy for an automated dispenser (Lapta et al., 2014).

Levkivskyi et al. (Levkivskyi et al., 2020) are investigated the algorithms of data mining, which on the basis of rules and calculations allow the creation of a model that analyzes data by searching for certain patterns and trends. Through the study of data mining algorithms, models and methods have been developed to determine the impact of some chronic diseases on others. The developed methods were implemented in the system of intelligent data processing. The conducted research testifies to the prospects of using methods of data mining to improve the quality of medical care for patients.

The research conducted by Bolodurina et al. (Bolodurina et al., 2020) aims to develop and numerically solve the problem of optimal glycemic control in patients with type 1 diabetes mellitus by insulin therapy based on the conditions of optimality for non-smooth systems with constant delay in the phase variable.

In the article by Karpel'ev et al. (Karpel'ev et al., 2015) the basic mathematical models of the biological control system of plasma glucose concentration are presented.

Palumbo et al. (Palumbo et al., 2013) offers a method focused on the most important clinical / experimental tests conducted to understand the mechanism of glucose homeostasis.

The dynamic behavior of a mathematical model, confirmed by experimental data, is studied by Trobia et al. (Trobia et al., 2022) which takes into account the relationship between glucose and insulin concentrations.

Shabestari et al. (Shabestari et al., 2018) presented a new mathematical model to describe the interaction between glucose, insulin and β-cells. The results showed that the system shows different behaviors under different conditions and is able to explain the interaction between glucose, insulin and β-cells.

4 MATERIALS AND METHODS

4.1 Methods and Metrics for Modeling an Automated Diabetes Control System

To develop a system of automated control of diabetes, it is necessary to define and implement methods for collecting input data on the patient's condition in real time. These data can be divided into two groups: streaming and constant. Streaming data require regular input and include blood glucose, alcohol, carbohydrates, weight, insulin, time and date, place of administration, physical activity, stress and illness. The constant data include such indicators as age, gender, type of diabetes.

Some of these data can only be obtained by manually entering it by a patient, others can be obtained automatically. Information about blood glucose can be obtained in two ways:

- after measuring blood glucose with a glucometer. A patient can either enter data manually or synchronize data with the system using Bluetooth technology (if supported by the meter);
- with a continuous glucose monitoring system. The monitor measures blood sugar every 10 seconds and records the average value every 5 minutes.

After measuring the weight, the patient can either enter the data or synchronize the data with the system using Bluetooth technology (if supported by the scale).

Information about physical activity has a different nature of collection, one of which is the synchronization of data from an external device such as a fitness tracker – a gadget that, in most cases, is worn on the hand and has built-in sensors that monitor activity during the day, including: number of steps, heart rate, sleep, calories burned, etc. An analogue of a fitness tracker is data collection using an application installed on the user's smartphone, or the user can simply enter data about daily activity manually.

If the data is entered manually, also the time and date are required to be entered. If the data comes from other devices or applications, it already contains time and date information.

For developing the mathematical module of the system metrics and methods for obtaining them were determined.

Sokol et al. (Sokol et al., 2014) proposed the principle of applying mathematical modeling to calculate optimal insulin therapy. Bhonsle and Saxena (Bhonsle and Saxena, 2020) analyze various mathematical models – despite the large number of mathematical models, they are all based on one of two original basic models: the model of the oral glucose tolerance test (OGTT) developed by Beaulieu in 1961 and the model of the intravenous glucose tolerance test (IGTT) by Bergman-Kobelli (Bergman et al., 1979). The Beaulieu model is narrow in use, in particular, it is generally unsuitable for describing the exponential decline of the glycemic curve of IGTT. The main disadvantage of the IGTT model, in contrast to the Beaulieu model, is that insulin is an input variable, the value of which is determined clinically.

The mathematical model proposed by Shirokova and Shirokov (Shirokova and Shirokov, 2006) is based on the ratio of glucose balance and insulin concentration in human blood over a certain period of time and improved by Bolodurina et al. (Bolodurina et al., 2020).

Therefore, the experimental determination of glycemic characteristics of insulin is as follows: knowing the initial level of glucose in the blood, as well as its integral characteristics, it is possible to choose the right amount of insulin.

4.2 Design and Developing the Algorithms of the System

For design and developing the automated diabetes control system functional requirements were defined:

- User registration and authentication must be provided in the system;
- Data storage: the system must store information and allow the user to manage it;
- Keeping a diary of self-control: entering and editing data of physical activity, medication and food;
- Analytics review: the system should provide the ability to review analytics for the selected period.

The algorithm of the automated diabetes control system is presented in figure 1. First, the user gets to the authorization screen, if he is registered, he can immediately pass it and get to the main screen. Otherwise, it is necessary to go through the registration process by filling out a standard form, the entered data are checked for validity and entered into the appropriate collection in the database.

Once on the home screen, the user can immediately view the statistics. The user can also go to the screen with analytics, where the information for a specified period is displayed. To work with entries, the diary screen with the functions of viewing, adding, deleting and editing entries is available. It is possible to set user settings, medication and glucose level. The data entered by the user when making changes to the settings or when working with diary entries are entered into the database.

On the main screen it is possible to add a new diary entry by clicking on the correspondent button. On the opened modal window with a form current time and date are passed. After the user enters the data, validation and synchronization with the database are performed and the user is redirected to the home screen

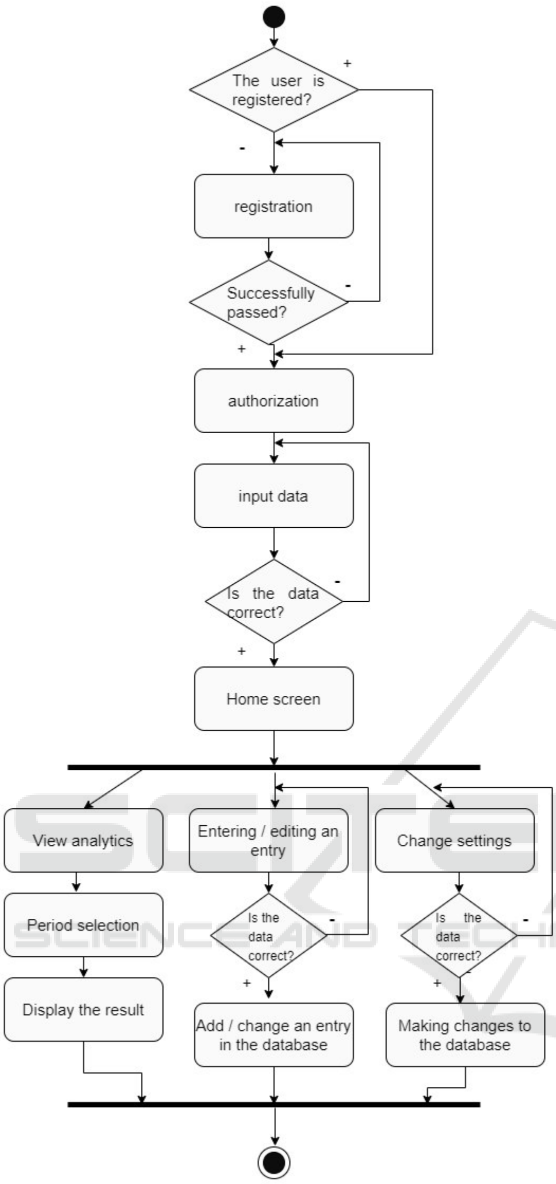

Figure 1: Activity diagram.

and methods are called to update the statistics based on the entered data.

The analysis of functional requirements allowed us to identify the following entities of the developing process. Figure 2 shows a class diagram.

Some classes shown on the diagram are described below.

- Home – a class of the main screen of the application. It has the following methods: ionViewDidLoad – this method starts after loading the screen and initializes the methods for updating statistics, updateStats – updating statistics for the week, dailyStats – updating statistics for the day, prepareStats – preparing statistics for the week, filterByDate – filtering diary entries by date, newNote – create a new diary entry, getFormatedDate, getTime – get the date and time, showHelp – display help information.
- Diary – a class for work with the screen of the system. It has the following methods: ionViewDidLoad – this method is started after loading the screen and initializes the methods for updating the list of entries, editNote – editing the entry.
- NewNotePage – a class for work with the modal window of adding and editing entries. Its methods – showDatePicker, showTimePicker – display forms for selecting the date and time, add, edit and delete for making corresponding operations with entries.
- Analytics – a class for work with the analytics screen. It has the following methods: ionViewDidLoad – it is called after loading the screen and initializes methods for analytics update, updateAnalytics, prepareReport (analytics data preparation), filterByDate (filtering entries by date), getFormatedDate, setFormatedDate, showDatePicker (getting and setting dates, date selection form correspondingly).
- Settings – a class for work with settings.
- Insulin-settings and Glucose-settings are classes for work with medicine and glucose settings. They have the following methods: ionViewDidLoad – the method is called after loading the screen and loads the settings, ionViewWillLeave – the method is called before closing the screen and saves the changes in the settings.
- Personal-settings – a class for work with personal set-tings. The class has the following methods: ionViewDidLoad, ionViewWillLeave, showDatePicker.
- Login is a class for the user authentication screen. It has a method login for user authentication.
- Register is a class for the user registration screen. It has a method register for new user registration.
- SettingsProvider – a class for working with user set-tings in the database. Its methods: getSettings – to get set-tings from the database, updateSettings – to update the settings in the database, addNewUserSettings – to create a document with the settings of a new user.
- NotesProvider – a class for working with user diary entries in the database. Its methods are getNotes – to load all user entries from the database, addNewNote – to add a new entry to the database, editNote – to update the entry in the database, deleteNote – to delete the entry from the database.

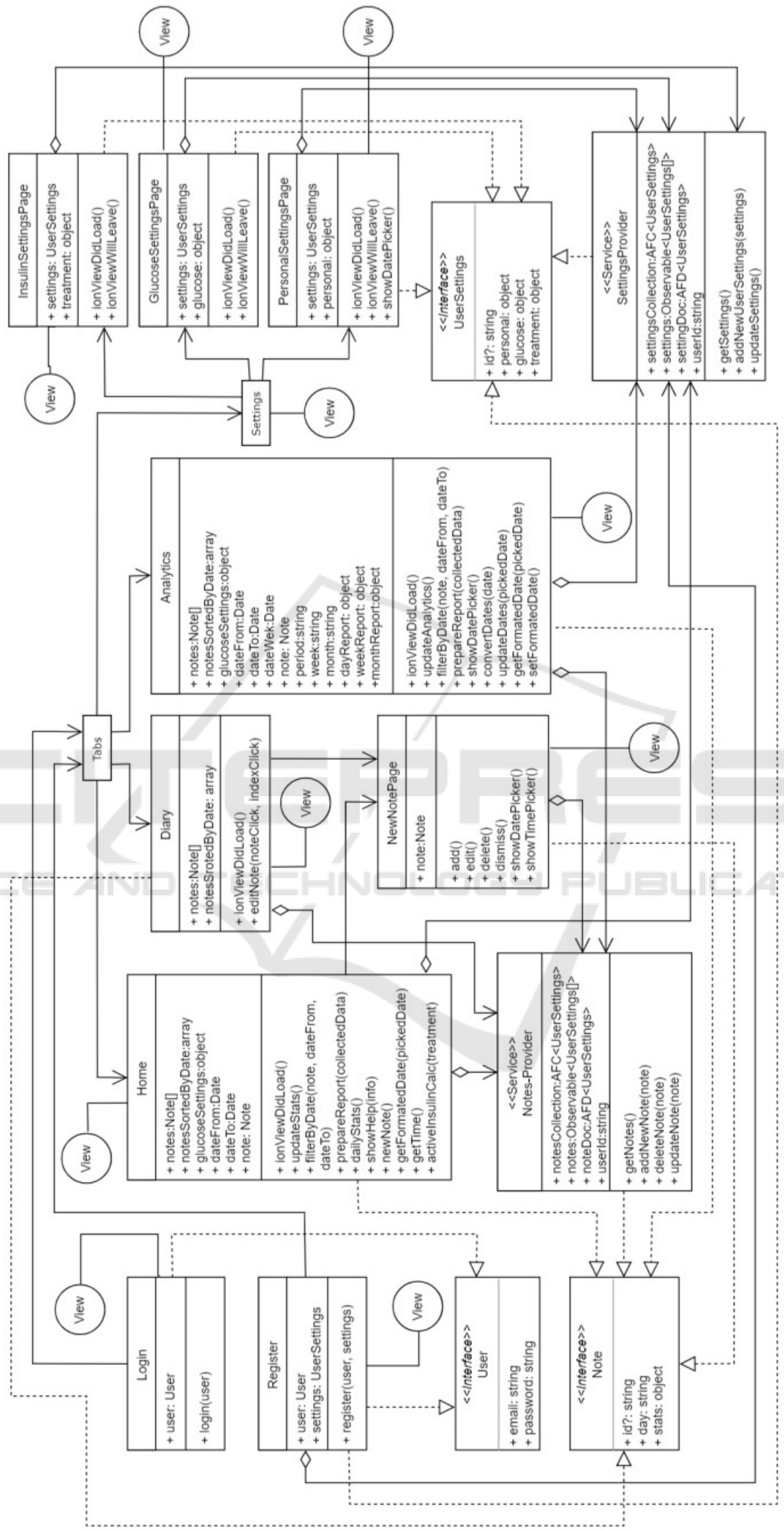

Figure 2: Class diagram.

Thus, the developed application has the functionality of making and editing entries in the system, medicine selection, obtaining analytics, data synchronization between devices, provided by the methods of the components Home, Diary, NewNotePage, Analytics, Settings, Login, Register, Personal-settings, Insulin-settings, Glucose-settings, SettingsProvider, NotesProvider.

Functions in the class Analytics are used to perform analytics. The code snippet is below:

```
updateAnalytics() {
this.notesForAnalytics =
this.notesSortedByDate.filter(note =>
this.filterByDate(note,this.dateFrom,
this.dateTo));
        let report;
        let collectedData = {
        noteCounter: 0,
        glucoseCounter: 0,
        glucoseSum: 0,
        hiLowCounter: 0,
        bolusInjectionCounter: 0,
        basalUCounter: 0,
        bolusUCounter: 0
        }
    this.notesForAnalytics.forEach(function
    (noteScope, i, notes) {
    noteScope.stats.forEach(function(note, i,
    notesFromScope){
    collectedData.noteCounter++;
        if(note.stats.glucose){
            collectedData.glucoseCounter++;
            collectedData.glucoseSum +=
            parseFloat(note.stats.glucose);
            if(note.stats.glucose <
            this.glucoseSettings.lowLevel
            || note.stats.glucose >
            this.glucoseSettings.hiLevel){
            collectedData.hiLowCounter++;
        }
    }
if(note.stats.bolus){
collectedData.bolusInjectionCounter++;
        collectedData.bolusUCounter +=
        parseFloat(note.stats.bolus);
        }
        if(note.stats.basal){
        collectedData.basalUCounter +=
        parseFloat(note.stats.basal);
        }
}.bind(this));
    report = this.prepareReport(collectedData);
        if (i === 0){
        if (noteScope.day === this.day) {
            this.dayReport = report;
        }
        this.weekReport = report;
        this.monthReport = report;
        } else if ( i <= 6){
            this.weekReport = report;
            this.monthReport = report;
            } else {
            this.monthReport = report;
        }
        }.bind(this)); }
```

To store and access system information a database was designed. It consists of three main collections (User, UserSettings, UserNotes) (figure 3).

5 RESULTS

After starting the automated diabetes control system, the login screen is shown, where the user must login or register by clicking on the registration button. After successful authentication the main screen is displayed (figure 4) with statistics of the main indicators for the week and for the current day, namely: bolus insulin per day, the amount of active bolus insulin at the moment, the number of hypo/hyperglycemia for the current day, average sugar level in seven days, mean deviation of sugar in seven days and the amount of hypo/hyperglycemia in seven days in percent. By clicking on these indicators, the user can get reference information (figure 4).

On the main screen there is a button to create a new diary entry. By clicking on it a modal window with a form is opened. Navigation is carried out through four tabs: Home screen, Diary, Analytics, Settings. On the screen of a diary (figure 5), all entries sorted and grouped by date and time are displayed as rows of cards with entered metrics.

By clicking on any entry, a modal window is opened to edit or delete the entry (figure 6). This window has a form with all the necessary fields for filling: medicine, food, activity, sugar level. The user can also choose the time and date of the entry. In editing mode of an entry, a button for deleting an entry appears in the navigation bar with a dialog box to confirm the deletion of the record.

On the screen of analytics the user can choose the desired period of a report, namely: one day, seven days and thirty days. Also, the date can be specified from which the data will be calculated (figure 7).

The screen with settings displays the user's email and a list of settings groups: personal settings, glucose settings for adjusting glucose levels for hypo/hyperglycemia, medication settings for choosing medications. There is also a login button in the navigation bar.

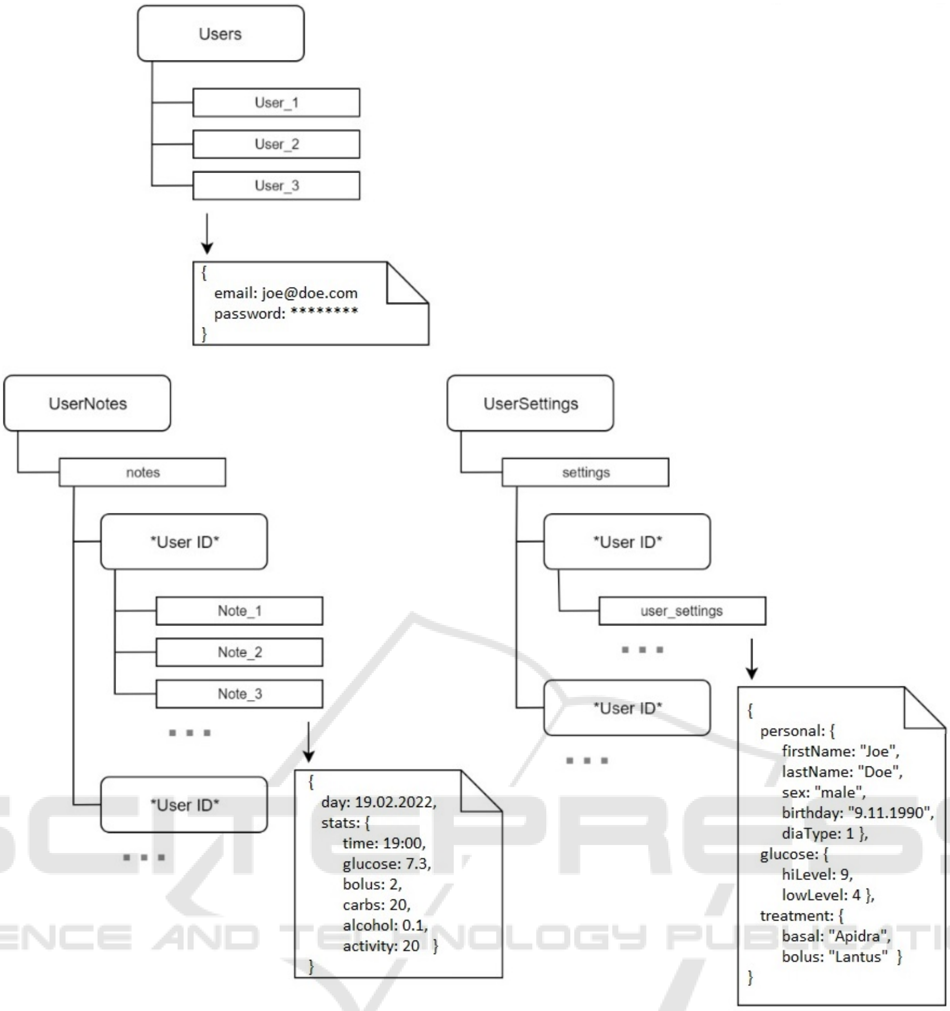

Figure 3: Database schema.

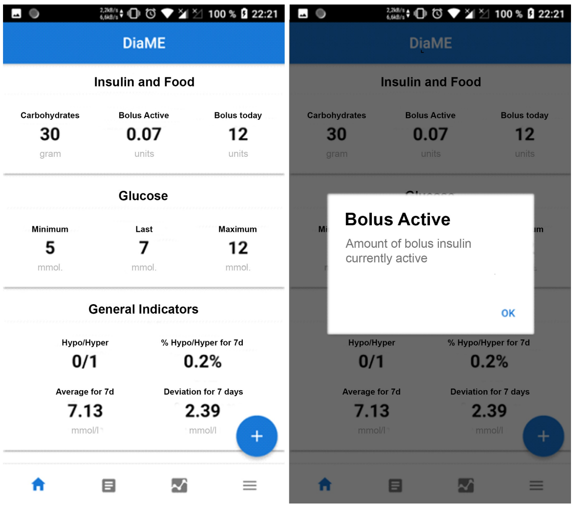

Figure 4: Home screen. Reference information.

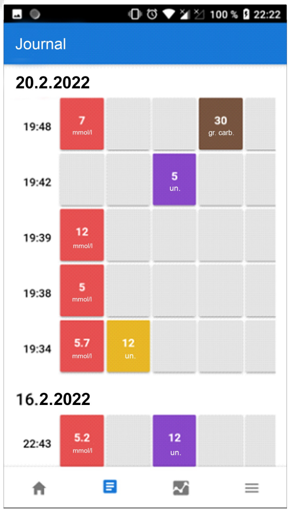

Figure 5: The screen of a diary.

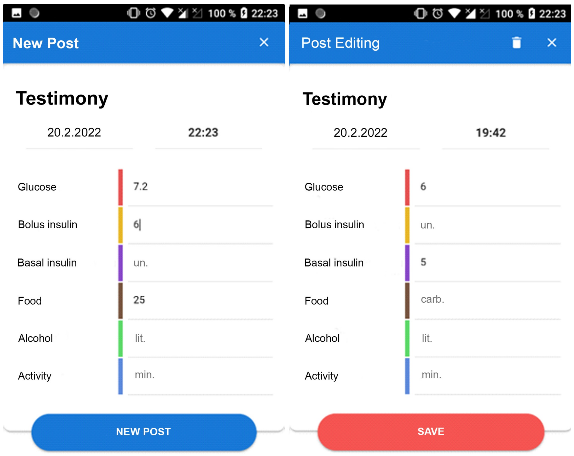

Figure 6: The forms for creating and editing entries.

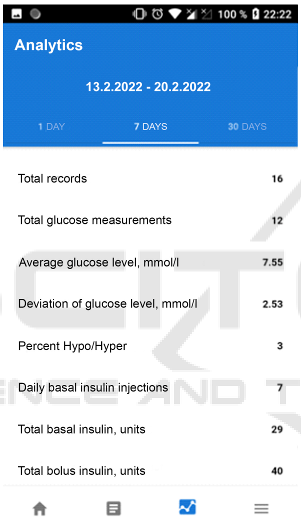

Figure 7: The screen of analytics.

6 CONCLUSIONS

It is estimated that diabetes is the cause of one in nine deaths among adults aged 20-79. Prevention of diabetes and its complications is important, especially in middle-income countries, where the current impact is estimated to be greatest (Saeedi et al., 2020).

As a result of the research, an analysis of the problem of diabetes was conducted. The basic metrics and methods of production of these metrics for the mathematical module of the system are determined. The functional requirements for the automated disease control system were analyzed. Algorithms of the system functions were defined and described, the order of interaction of classes during the execution of the programing code was determined and the system of automated control of diabetes mellitus was developed.

In the process of development and testing, we consulted with doctors and took into account their recommendations. The system has received positive feedback from diabetes patients who continue to use it. The developed software product is ready for use.

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