An Integrated Monitoring System for Managing Diabetes Patients Using Mobile Computing Technology

Mashael S. Bin-Sabbar and Mznah A. Al-Rodhaan

***ABSTRACT*- Diabetes is a chronic disease that needs to be regularly monitored to keep the blood sugar level within normal ranges. This monitoring depends on a diabetic treatment plan that is periodically reviewed by the endocrinologist. Patients have to do the medical checkups and examinations from time to time. According to the result of this medical checkups and examination, the endocrinologist may need to modify the treatment plan. The frequent visit to the main hospital seems to be tiring and time consuming. Mobile devices have an impact role in this problem by remotely monitoring the diabetes patients. In this paper, an integrated monitoring tool is presented consisting of three main units: patient, care center, and hospital units. The system provides a daily monitoring and monthly services. The daily monitoring includes recording the result of daily analysis and activates to be transmitted from a patient's mobile device to a central database. The monthly services require the patient to visit a nearby care center for medical examination. The result of this visit entered into the system and then synchronized with the central database. Finally, the endocrinologist can remotely monitor the patient record and adjust the treatment plan and the insulin doses if need.**

***Index Terms*—Diabetes, electronic monitoring, remote monitoring, ubiquities healthcare.**

I. INTRODUCTION

Diabetes Mellitus (DM) is a chronic disease that is considered to be a metabolic disorder [1]. Diabetes is caused by either the absent of insulin or inability to utilize the produced insulin. Age, family history, body weight, and having previous gestational diabetes are some factors making the person easy target of diabetes. It is classified within three categories: Type1 diabetes mellitus (T1DM); which is the result of not producing insulin, Type2 diabetes mellitus (T2DM); which is the result of ignoring insulin by the cells, and gestational diabetes which diagnosed in some pregnancies. In fact, diabetes needs to be treated either by just modifying life style, or by medications and injections. This treatment is very important to prevent fatal complications. Also, patients who have diabetes need to measure their blood level by daily using a glucose meter. In addition, they have to do the HA1c test every 3 to 6 months to allow the endocrinologist to evaluate the treatment plan and adjust the dose.

Manuscript received July 24, 2012; revised August 09, 2012.
Both authors are from the Computer Science Department, College of Computer and Information Sciences, King Saud University, Riyadh, Saudi Arabia.{Msabbar, rodhaan}@ksu.edu.sa

Mobile computing can improve the quality of the patients' life by providing systems that help diabetes patients to monitor and control their diseases [2]. These applications can help the endocrinologist by providing a remote monitoring to the patient. Database technologies can be combined with communication technologies to present an integrated diabetes monitoring tool.

Nowadays, many researches are proposing different architecture and system design for diabetes monitoring system. One of these proposed systems is SMARTDIAB [1] which is proposed by S.G. Mougiakakou et al. in 2010. They combine state of the art approaches in database technologies, communications, simulation algorithm and data mining. SMARTDIAB was consisting of two units: patient unit and patient management unit. The patient unit feed the system by passing information and gets the response.

In this paper, we will improve the SMARTDIAB by building a system of three units: patient unit, endocrinologist unit, and general physician unit. In addition, we increase the strength of our proposed system by adding the HA1c test's result which helps the endocrinologist to efficiently evaluate the treatment plan. The accuracy of the data is achieved by depending on electronic data input for blood glucose levels' readings. And since the authority is a sensitive criterion in any health care monitoring system, we define three actors in the system with three associated access rights.

This paper is organized as follows: Section II presents the problem statement and discusses the proposed system architecture. In Section III, Patient side solution is presented. In Section IV, we present the doctor side solution followed by discussion about the central database in section V. And in section VI we show the system evaluation. Finally, we summarize our work and highlight some future works in section VII.

II. PROBLEM STATEMENT AND PROPOSED SCHEMA

In this section we present the problem statement and the proposed scheme. First, we define the problem and present the real impact of diabetes on the human beings. We emphasize on the effort that rise from the regular medical examinations and tests. Next, we present our proposed scheme in details.

A. Problem Definition

Since diabetes mellitus is a chronic disease, it needs a regular monitoring to control blood sugar level. Seriously, this monitoring is very critical to prevent many fatal complications. According to the World Health Organization (WHO) [3] more than 220 million people worldwide have diabetes. In 2004, about 3.4 million people died from complications and consequences of high blood sugar. WHO expects that diabetes deaths will double between 2005-2030. For the economic side, diabetes mellitus economically has an impact on individuals, families, health systems, and countries.

Diabetes mellitus monitoring includes maintain healthy weight, physical activates, and regular medical examinations and tests. In fact, regular medical examinations and tests seem to be time consuming for both doctors and patients. Patients who live in neighboring villages face some difficulties to go down to the hospital in the city. They have to reserve a ticket or pass a road, reserve a place to stay in addition to the cost of the treatment if any.

Our proposed framework produces a diabetes monitoring system based on mobile platform. This system can assist diabetes mellitus patients to monitor their glucose level according to the glucose level readings, intake food, medication, and physical activities. Our system based on electronic data input, as well as manual data input. This is for accomplish data accuracy and follow-up daily activities at the same time. In addition, clinician-to-patient interaction is allowed by exchanging messages.

The proposed system has a dual-language capabilities. The new feature is Arabization. Most of the diabetes monitoring systems was available in English language only, where D.L. Katz and B. Nordwall were translated their system in Spanish [4]. Also we will allow an effective functionality to control the change in HbA1c Levels. Black sea tele Diab [5] was caring about this point, but it was a desktop based system specific for physicians.

B. Proposed System Architecture

The proposed architecture is consisting of three main units: the Patient Unit, the Center care Unit and the Hospital Unit. The Patient Unit is the starting point in the system. It contains the patient, the glucose meter, and the mobile device. The glucose level readings are electronically transmitted to the mobile device. Also, the patient can manually enter daily food intake, physical activities and information about some medications and injection. The system may alert the patient about injection time, special medicine reminder, date for medical examination and tests. The patient is able to chat with a GP in emergency cases or for inquiries. These conversations are done via exchanging messages.

The Care Center Unit represents the medical center in the patient hometown where the patient can visit instead of the hospital in the main city to do regular checks and medical tests and examinations. The general physician in the medical center is allowed to enter results of the HA1c test.

The Hospital Unit is controlled by the endocrinologist who can remotely monitor the patients' status, send advises, and take an action in urgent cases. The endocrinologist is the only actor who allowed modifying the insulin doses regarding to the daily glucose reading and the result of the HA1c test. These three units are integrated together forming a whole Diabetes Monitoring System. The interacting between these units is done by exchanging data.

Our proposed system is consisting of three layers: Presentation Layer, Service Layer, and Data Repository Layer. The Presentation Layer presents the system units' interface. The user can access the system interface by logging to the system and assigned an access rights. The Service Layer is the core of our system. It performs the services to the system units. Fig. 1 shows the system architecture.

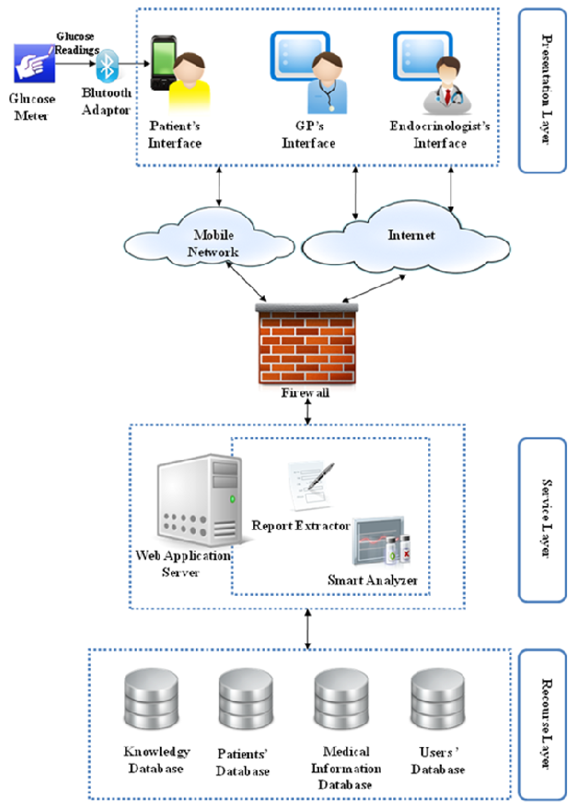

Fig. 1: Proposed System Architecture

It contains two main components: Report Extractor and Smart Analyzer. The Report Extractor service is inquired by the endocrinologist or the general physician. It accesses the Resource Layer and collect information from the requested database. Then, it formats this information and presents it to the requestor. The Smart Analyzer is responsible to analyze incoming data before send it to the

ISBN: 978-988-19251-6-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

database. This Smart Analyzer is depending on some values such as: MIN_Glucose_LEVEL, MAX_Glucose_Level, and HA1c value. Resource Layer contains the databases for the system. The system depends on many databases such as: medical information's database, patients' database, and users' database.

III. PATIENT SIDE SOLUTION

The Patient –Side Environment was implemented on the android using java programming language. Android SDK was used to setup the development tool and SDK add-ons. In the following subsections, we will overview some of the used android and java technologies and describe them in more details. The first technology was the use of the virtual device configuration. We choose HTC Desire as target platform and we set the virtual device configuration as SDK Platform Android 2.2, API8. After that we were able to use the emulator as a virtual device to run our application on it.

Second technology was Dual Language Support. Our project implementation was designed to support two languages; English language and Arabic Language. Each Patient can set their preferred language. This preferred selection is saved in the database. Once the patient logged in to the system his preferred language will be retrieved, and according to the preferred language the application will launched with that language. The design of our system is flexible so it can support more languages in future.

Bluetooth Connectivity is another technology had been used in our system. The Android platform support exchanging data over a Bluetooth network stack. The Android application access the Bluetooth functionality through the Android Bluetooth APIs. These APIs allow point-to-point feature by perform the following: Query local Bluetooth adaptor, scan for neighbor Bluetooth devices, Establish Radio Frequency Channels between the local adapter and the selected device, transfer data to and from other device[6]. Our selected glucose meter has an embedded Bluetooth sensor. It connects to the android application over a Synchronous Serial Port (SSP) profile with a well known Universally Unique Identifier (UUID). The SSP profile is a serial interface used for communication between two devices [7].

Also, Our system use remote communication with central database. The android application can handle communication with a remote MySQL database to authenticate patient log in information and also to retrieve/ update patient medical information in the database. The communication process with MySQL database is done by posting data using HttpRequest. First, the application has to make a connection with a PHP script which locates in the server. This is done by use HTTP protocol from the android application. PHP scripts are in the middle between the android application and MySQL database.

Finally, our system was providing send SMS. The patient can send SMS message to the endocrinologist throw the Android application. This can be done by using SMS Manager that manages sending a text message. In the Android script, the endocrinologist's phone number will be retrieved from the MySQL database. Then, the SMS Manger will be called to get the default instance of it. After that, the function sendTextMessage will be called to send the SMS message.

A. Android Application Activities

In this section, we will preview the features of our implemented Android Application. Android deals with the project interfaces as Activities. The activity is an application component that provides view which users can interact with the application [8].

In our android application there are many activities .The main Activity is named DiabMonSys.java. This activity is responsible to get the user log in information and authenticate this information. After the patient successfully logged in to the application, the patient will be allowed to choose from four features: My Services, My Information, Call Expert and Setting. Each of these features contains sub-functions in deep. My Services can runs: GluoseReadingActivity.java, IntakeFoodActivity.java, PhysicalActivitiesActivity.java and GlucoseInjectionActivity.java. The same is for My Information feature. It can run: MyDosesActivity.java, MyAppointment.java and GlucoseRanges.java. The Call Expert feature is an Activity in its own. We prefer to present it in the main screen because the patient may need it in urgent cases, so it has to be directly reachable.

Finally for the Setting feature, it contains two activities: ChangePasswordActivity.java and ChangeLanguageActivity.java. The main activity in our project launches log in screen with two data fields, user name and password. When the patient write the name in the fields, the Application will connect to the central database, authenticate the input information, and then if the patient authenticated, the patient id with the preferred language will be retrieved from the database. The patient ID will be used in the next activities, and the preferred language will be used to set the interfaces language.

In My Services Activity the patient can select from four sub-activities. First is 'Daily Glucose Reading Activity' which allows the patient to enter their daily readings. These readings can be entered either manually or via Bluetooth. After entering the glucose reading, the patient specifies whether this reading is pre-meal or post-meal. This is done because the application will analyze the glucose reading with the timed situation and then advice the patient what to do. The analysis of glucose readings is based on standards of medical care in diabetes [9-12].

Another service here is 'Intake Food and Physical Activities'. These two activities are based on the patient entry. The patient can select from a menu what he/she was eaten and the amount. The calculation of the calories is based on Food and Nutrition Information Center [13]. After calculation is done, the patient will be advised about what they have to do for example: eat some fruit, drink soft drinks, have a walk and so on.

The final service in 'My Services Activity' is 'Glucose Injection'. As a treatment of hypoglycemia the patient have to take the glucose injection. If the patient takes this injection, the endocrinologist may decide to change the next few insulin doses for some time. So, our application will allow the patient to enter this information and the endocrinologist will be alerted about that in order to modify the insulin doses if needed.

In My Information activity, we allow the patient to preview the insulin doses, the appointments, and the average of his glucose readings. 'My Doses Activity' will retrieve the insulin doses from the MySQL database and present them to the patient. When the endocrinologist modifies these doses, the new values for these doses will update in the patient side too. Also, the patient will present the time he/she can start to take this dose and for how many months. 'My Appointment Activity' presents the patient with their next appointment. If the status of this appointment is 'urgent', patient will be alerted about this appointment. Finally is 'My Glucose Reading Rang'. This activity will show the patient his/her average range for the glucose reading for the last 7,14 and 21 days. This is to give the patient an overall vision about the glucose level.

In addition, sometimes the patient needs a quick advice from the endocrinologist. In our application, we allow the patient to send SMS message to the endocrinologist. In the MySQL, each patient is associated with an endocrinologist who monitors the patient diabetes. Once the patient starts 'Call Expert Activity', the mobile number of this endocrinologist will be retrieved from the MySQL. And then, the text written by the patient will be sent by the android application to that number. After that, the endocrinologist advises the patient as needed.

Setting is the last activity in the patient side. The patient will be able either reset the account password or change the preferred language. If the patient tries to change the password, he/she will be prompted to enter the previous one. If they are matched, the patient will be allowed to enter a new one and this new password will be stored in the MySQL database. Also, the patient can select wither he/she prefer English language or Arabic. These changes will be stored in the central database for future logins.

IV. DOCTOR-SIDE SOLUTION

In this section we will discuss the implementation environment on the doctor-side Application. Also, we will introduce the system privileges that supported by the doctor-side application and the functions that allowed for each privilege. Finally we will discuss how do we use Java Database Connector (JDBC) in our system to communicate with the central database.

A. Implementation Environment

This application side was implemented using java programming. Since this side is straight forward retrieving form the MySQL database and writing to it, the java programming was a good solution for that. The doctor-side application needs an extra library which is the JDK library available as a default with any java application. The extra library is called mysql-conetor-java-x.x.x-bin.jar, where x.x.x is version number. This library is needed to facilitate communication with MySQL database. By using this java library, we can prepare SQL statements and executes them directly within the code. This is eliminates the need of PHP scripts here. We divided the functions that perform the tasks as web services. Each of which is specialized to do something in the database.

B. Application privileges

In the MySQL database, the doctor's information contains privilege field. This field may contain one of the two values: 'ENDO' for the endocrinologist and 'GP' for the general physician. If the doctor has 'ENDO' privilege, this means that he/she have higher scope of functionality. The endocrinologist can have the following functions:

- Preview patient record: shows record number, patient name, patient ID, Date of birth, and phone number.
- Glucose Injection: present the injection dose and whether the patient took it or not. The Endocrinologist has an ability to edit the glucose injection dose.
- Physical Examination: shows the last examination date, the HA1c result and physical examination result. The Endocrinologist has an ability to enter new test result for a specific patient.
- Appointments: shows the last visit, and the next visit. Sometimes the endocrinologist needs to make an urgent appointment according to some results, HA1c result for example, so the endocrinologist will have authority to make an urgent appointment by specifying the date and the priority for this appointment.
- Insulin Doses: presents the doses for the insulin injection, the start date for these doses and for how many months. The endocrinologist has the ability to edit these doses and accept the changes.

The main idea of the project was to add a general physician role to the system to balance the load with the endocrinologist, the general physician will have a preview privilege with an authority to insert new test examination. Each test examination result is associated with the doctor id for the doctor who did it. So, the endocrinologist will know who did this examination for the patient.

C. Java Database Connector (JDBC)

The JDBC API is a java API that facilitate everyday access relational database [14]. By using JDBC the application can connect to the MySQL database, send queries and update statements to the database, and retrieve results from the executed queries. In our application, we deal with the database as a spirit class which we call "database". The constructer of this class receives the database host as a string variable. Then, a connection with the database will be established in order to be ready for the coming services.

This can be done by calling the drive manager of JDBC as the following:

con = DriverManager.getConnection(Host, "root", "");

Where 'con' is variable connection, 'Host' is the transmitted parameter to the constructer. After that, whatever the services are there will be a function in this class that performs the task. Each service receives a query as a string and some needed parameters to execute the query or the update.

V. CENTRAL DATA BASE

In our project, we build central databases between the patient-side application and the doctor-side application. These central databases are installed using WampServer to synchronies the information between the clients. In our project, there are two databases: 'accounts' database and 'dms' database. 'Accounts' database contains the users log in information for the both application sides, e.g. patient-side application and doctor-side application. These data is used to authenticate users log in information. Once the application is authenticate the user, it will connect with the 'dms' database. 'Dms' database contains all the system relational tables such as: patient, doctor, appointment and so on.

VI. SYSTEM EVALUATION

This section will discuss the evaluation of the integrated system. Our project is considered to be e-health system. And in our evaluation will apply the criteria of e-health evaluation [15].

A. What to evaluate?

There are some important areas that have to evaluate to ensure that the system is successful. First is to ensure that the system is useable. For the system to be useable means that the users can achieve the target goal easily. The usability is important in e-health system because if the system is not useable, the patient will never get the benefit of the system. Cost implications are important in evaluation e-health applications [15].

B. Usability Evaluation

Since the target user for our mobile application is diabetes patients, we consider in our design to be easy to use and flexible. We put in our consideration that the patient may have vision problems, may be an elderly, or may have an urgent problem. So, in our user interfaces design, we try to follow the mobile application usability check list [16].

C. System Strength

Since our integrated system is design as client-server model, it has many strength points that make it better than some existing software. These strength points are:

- Language independent: Our system interfaces is design based on language dictionaries. Currently, we support two languages. In future, it can be contains many languages just by building the XML language dictionary.
- Shared Resources: The database in our application is installed in a WampServer. And the resources in this database are shared between the patient side application as well as doctor side application.
- Database isolation: Since the resources in the database are very critical, we limit the insertion to the database according to the authority. System administrator is the one who is able to insert/edit/delete users and equipments information, but not medical ones. The Endocrinologist is the one who is responsible to entered/update the critical medical information, such as: insulin doses, urgent appointments, etc. The GP is only able to enter examination results. This ensures the right person is dealing with the right information.
- Cost implication: As Android offers many mobiles with variety in cost. The patient will be able to select a smart phone that is within his/her limitation. Currently, the mobile-side application was tested on HTC Desire which runs on Android 2.2. And regarding the glucose meter, we use Myglucohealth glucose meter/ wireless kit, it costs about $89. This is a mediate cost between the public.

VII. CONCLUSION

In this paper, we discuss our implementation of a diabetes monitoring system for managing and monitoring diabetes patients. The specification of our implemented project is based on Android platform. The architecture of the system is depends on three units: the patient unit, the endocrinologist unit, and the general physician unit. These three units are working together forming an integrated diabetes monitoring system.

Our implemented system provides the patient with many facilities to better monitoring his/her diabetes. Also, the endocrinologist is another aim in our system that we try to reduce the amount of regular medical checkups and examinations he/she do for every diabetes patient. We achieve this goal by adding a general physician who can do this medical checkups and examinations and feed the system with the results. The endocrinologist can access the system and request a report for a certain patient. He/she can modify the insulin doses and the treatment plan if needed.

Our Implemented system is divided into three environments: Patient-side, doctor-side, and central database environments.

The patient environment is implemented using Android SDK. In patient-side application, the patient is able to do many services. First, the patient is allowed to feed the system with information throw My Services Activity. He/she can enters daily glucose reading, enter intake food, enter physical activities, and enter glucose injection information. Also, the patient is allowed to preview patient information through My Information Activity. Patient can preview the insulin doses, the appointments, and the glucose level ranges. In addition, the patient can make an urgent call to the endocrinologist throw sending SMS message. We add two personal activities which are: change

ISBN: 978-988-19251-6-9
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

my password, and change my preferred language. The doctor-side implementation is based on java programming. We use JDBC to facilitate communication with the database. In side Implantation, the interfaces in depending on doctor privilege. The doctor may have 'ENDO' authority which allows patient to preview and edit their own record. On the other hand, patient's GP will have authority to preview patient record in addition to enter physical examination results.

In our Implemented project, we use WampServer to create MySQL database. Our database is central between the patient-side application and the doctor-side application. We build an administer tool to manage the insert, update or delete users record in the database.

REFERENCES

[1] S.G. Mougiakakou et al. , SMARTDIAB: a communication and information technology approach for the intelligent monitoring, management and follow-up of type 1 diabetes patients, IEEE Transactions on Information Technology in Biomedicine: A Publication of the IEEE Engineering in Medicine and Biology Society, vol. 14, (May. 2010) , 622-633.

[2] M. Lee, T.M. Gatton, and K.-K. Lee, A Monitoring and Advisory System for Diabetes Patient Management Using a Rule-Based Method and KNN, Sensors Magazine, vol. 10, (2010) , 3934-3953.

[3] American Diabetes Association. Internet: http://www.diabetes.org/ , (2011) [June, 7, 2011].

[4] Medical News Today. Internet: http://www.medicalnewstoday.com/, 2001 [16, May, 2012].

[5] R. Graham, Self-Monitoring of Blood Glucose (SMBG): Considerations for Intensive Diabetes Management, Pharmacy and Therapeutics Magazine, vol. 30, (2005).

[6] Android Developers: Bluetooth. Internet: http://developer.android.com/guide/topics/wireless/bluetooth.html , (2012) [January, 4, 2012].

[7] Microchip Synchronous Serial Port, Microchip technology Inc, (1997), 15-30.

[8] Android Developers: Activities. Internet: http://developer.android.com/guide/topics/fundamentals/activities.html, (4 January 2012) [16, May, 2012].

[9] National Diabetes Information Clearinghouse (NDIC). http://diabetes.niddk.nih.gov/. 7 (December 2011) [16, May, 2012].

[10] Living with Diabetes. Internet: http://www.diabetes.org/living-with-diabetes/ , (2011) [16, May, 2012].

[11] Rubin, Diabetes for Dummies, 3rd Edition, Welly Publishing, Inc.,(2008).

[12] Medicine Net: Hyperglycemia. Internet: http://www.medicinenet.com/hyperglycemia/page2.htm , (2012) [16, May, 2012].

[13] Food and Nutrition Information Center. Internet: http://fnic.nal.usda.gov/nal_display/index.php?info_center=4&tax_level=1 , (27 December 2011) [10, May, 2012].

[14] JBDC database Access . Internet: http://docs.oracle.com/javase/tutorial/jdbc/overview/index.html , (2011) [4, January,2012].

[15] Q. Le, Evaluation of E-health, Honours thesis, University of Tasmania, (2007).

[16] Mobile Application Usability Check List, Internet: http://www.keepitusable.com/keepitusable-mobile-app-usability-checklist.pdf , (2011) [16, May, 2012].