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Design of a Large Scale Community-Based Self-Management System for Diabetes Mellitus

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Abstract. This paper presents the ongoing development of a community based, self-management system for diabetes mellitus, which incorporates web-based, SMS and mobile-terminal functionalities. SMS represents the first stage of our system development as it is widely available on all mobile phones, convenient and becoming increasingly popular. We discuss past findings and the need for such a system, as well as design, implementation and system architecture. Poor self-management of diabetes is associated with progression into more complex health issues, manifesting as a significant public health burden and impacting negatively on an individual's quality of life. This approach recognizes that telehealth systems will play an increasingly pertinent role in health systems worldwide.

Keywords. Diabetes, short message service, SMS

Introduction

Diabetes is a serious, chronic condition where poor self-management of blood glucose levels is associated with progression into more complex diseases, incurring significant costs for the health system. In 2004, an estimated 3.4 million deaths worldwide resulted from consequences of high blood sugar [1], often occurring due to poor diabetic management; hence good self-management, accurate recording and reporting to the clinician is paramount. In diabetic patients, accurate self-monitoring is the initial and most fundamental step in achieving positive self-management outcomes. Current practices commonly involve patients keeping a logbook of blood glucose levels and insulin injections, which are presented to the healthcare professional at clinic visits.

With the growing prevalence of diabetes, estimated to affect 346 million people worldwide [2], there will be an increasing demand for effective telehealth solutions. A mobile terminal-based system provides an ideal platform for facilitating the collection, collation and statistical analysis of blood glucose measurements, insulin therapy administered (where appropriate), glyceated haemoglobin (HbA1c) levels and other relevant data.

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SMS technology is widely available on all mobile phones, highly portable, easily accessible and relatively simple to use. It provides additional information such as caller ID and time, which can help simplify the data input process. Other mobile input modes, including iPhone and Android applications, interactive voice response (IVR) telephone systems, or a web portal, may appeal to different users.

Past research indicates that such an approach to diabetes self-management would be both effective and accepted [3,4]. Despite this, literature has failed to describe a robust and scalable technical system to support the large scale deployment of such a service to the community. There has been minimal literature regarding the implementation of previous systems, particularly with reference to SMS input. Past trials have also been limited by small sample sizes and the vast majority involved frequent healthcare provider input. Consequently, we believe many of these previous approaches involved using a mobile phone to receive SMS messages, followed by the manual process of data entry into a database for statistical analysis, with a high level of healthcare provider involvement.

This paper presents the ongoing development, with regards to design and technical implementation, of a large scale, community-based self-management system for diabetes. We initially focus on achieving a user-friendly approach to SMS input methods. The system is designed to be a free, community-based service, capable of handling a large number of users, with the potential for multiple input modes, online reporting and group management for medical professionals.

1. Background

1.1. Diabetes Management and the Role of Telehealth

The chronic nature of diabetes means that good self-management is paramount in achieving good outcomes. Motivation to self-care is critical for improvements in glycemic control [5], and poor self-management is associated with progression into poor health outcomes, with a significant public health burden. Current practices include an emphasis on self-management education and frequent clinic visits. For many patients this includes regular monitoring of blood glucose levels, and for insulin-dependent diabetics, also includes insulin therapy; both of which are generally recorded in a paper-based diary.

Health authorities hold significant expectations for telemedicine in the field of diabetes, as it has the potential to improve access to and quality of healthcare whilst reducing costs.

1.2. Mobile-Terminal Based Applications in Diabetes

The use of mobile-terminal based self-management systems in diabetes is not a new concept. A simple telehealth approach for diabetes management, with design objectives similar to our own, was described by Ferrer-Roca et al., [6], where 23 patients transmitted data such as blood glucose levels and body weight to a server over an eight month period via SMS. A good overall satisfaction rate and high acceptance by users suggests that SMS may provide a simple, fast and efficient adjunct to the management of diabetes. This system was the most consistent with the design of ours and highlights

the potential role of mobile applications in facilitating the data collection, processing and analysis procedures.

The design of past applications and their respective studies have varied markedly. Systematic review of 39 publications describing 28 different studies reports that users generally agree to the overall concept of these applications [4]. All of these studies involved patients regularly reporting glucose levels through a mobile device. Some more elaborate systems provide immediate help to patients in determining their insulin dose, based on formulas set by healthcare professionals [3]. Simpler approaches collect, collate and analyse data, automatically transmit data to a healthcare professional, and/or process data into a readily interpretable formats [3]. In one study where both web browsers on PCs and mobile terminals were available for data entry, mobile terminals accounted for >90% of total entries [7]. Young people in particular showed a marked preference for a SMS-based system compared to a paper-based diary or email [8]. However, some applications were considered too time consuming for those already used to a paper-based diary, particularly amongst the older population [9].

Meta-analysis amongst 1657 patients from 22 trials showed that mobile phone interventions for diabetes self-management reduced HbA1c levels (a longer term measure of glucose control) by a mean of 0.5% over a median of six months [10]. Studies included in this analysis facilitated self-monitoring and reporting of blood glucose data alongside some sort of management program, intervention, education, and/or continued reinforcement.

It has been suggested that web-based management systems can be as effective as face-to-face guidance and treatment in caring for diabetic patients [11]. Where reporting of glucose and other parameters, such as daily exercise and diet, were combined with regular recommendations for individualized diabetes management by a multidisciplinary team, mean HbA1c improved from 7.5 ± 1.5 to 7.0 ± 1.1% (P=0.003) after three months [11].

1.3. Successful Design Features and Best Practices

Human engineering factors underpin the design of successful telehealth solutions. As self-management of diabetes occurs on a daily basis, minimal time requirement and ease-of-use is critical [4]. Some previous applications have been considered too time consuming, particularly by those used to a paper-based diary [9]. In one study, adolescents considered the use of an application too time consuming despite requiring less than a minute [12].

In past studies where manual data input was required, frequency and consistency in transferring glucose values varied markedly between studies and individual patients [5]. In general, patients who transferred more glucose values tended to be more motivated, and achieved better outcomes [5]. The need to report data was considered to have a reminding effect [8,9,13].

Patients who use conventional logbooks sometimes do not register all their results, but only the good ones and this is probably the case with a mobile system [5]. Previous systems have been criticized for the inability to retrospectively enter data [6]. Unregistered measurements do not benefit the doctor or the patient—selective reporting may be misleading.

2. System Description

We sought to design a community-based, user-oriented system for the self-management of diabetes, taking into account user perspectives of both patients and healthcare professionals. We define this as a self-management system due to the system's reminder functionalities and its capacity for additional features. The system incorporates web-based, SMS and mobile application (iPhone, Android) capabilities, with the initial focus on SMS data input linked to a Linux-based MySQL database. This was to be a free service (except the costs of mobile/internet subscriptions), simple to use, with an intrinsic level of flexibility allowing patients and doctors to use the system in the manner they wished.

2.1. Patient Perspectives

Patient accounts are linked to an email address and one or more mobile phone numbers. Patients report regular blood glucose levels by texting the numerical value to a mobile number, which enters the data based on the time received and mobile number received from. Similarly, insulin dependent diabetics can also report the level of insulin administered by texting two values – a blood glucose level, and an insulin dose. Additional information such as diet, exercise, medications and other lifestyle factors may also be entered. Data may be entered retrospectively or edited through the website if incorrect data values are sent. Statistical analysis and graphical representation of data can be accessed by the patient. We have also designed an opt-in reminder system, where SMS reminders can be sent to the patient at regular times on a daily basis, or if data is not received by the server when expected.

We believe this system has the potential to replace paper diaries if used consistently. SMS reporting has an easy learning curve, and once habitual, is fast and efficient. The reminder system aims to reduce selective reporting and its associated problems. Furthermore, the regular input of data may have a reminder effect or can be considered a form of motivation.

2.2. Medical Perspectives

Medical professionals or healthcare clinics may have accounts linked to their patients, serving as a patient management system. This allows for easy access to patient data and is supplemented by the health provider's ability to enter additional information such as HbA1c levels, investigation results, interventions, directions and comments. Data analysis and modelling may provide useful information. Future possibilities include the integration of teleconsultations and the ability for doctors to send SMS messages to their patients through a web portal.

3. Design and Implementation

3.1. System Architecture

The system consists of multiple servers co-located in a carrier grade data centre for reliability. This includes a VMware ESXi [14] virtualization server hosting the main

web server as a virtual machine, two dedicated database servers and one GSM gateway (see Figure 1).

All servers were custom built and run on the CentOS Linux operating system [15]. The frontend website and portal were built using an open-source content management system Drupal [16], a powerful system that enables integration with our custom design backend database system and to write our own codes in the PhP programming language [17]. The website was set up as a virtual machine allowing us to increase allocated resources easily as necessary. Two database servers were built on dedicated servers rather than as virtual machines for performance reasons. The open source MySQL database [18] was run on both servers, holding the databases for Drupal and our custom designed diabetes management system.

A custom built, Linux-based 4-port GSM gateway was used to automatically receive messages from patients, to process and insert data into the database and to send SMS reminders. The open source voice over IP (VoIP) system Asterisk [19] was customized and integrated with the database. A specific hardware add-on card, OpenVox G400P 4-port GSM card [20], which can take four SIM cards, was installed in a dedicated server to build the GSM gateway. The first GSM gateway was deployed in Sydney and can serve Australia only. For other countries, the setup of local GSM gateways will be required, with SIM cards from local mobile carriers. As such SMS data input will initially be limited to Australia, whilst International users are welcome to use the web-based capabilities. However, SMS gateways around the world can be connected to the main system via virtual private networks (VPNs).

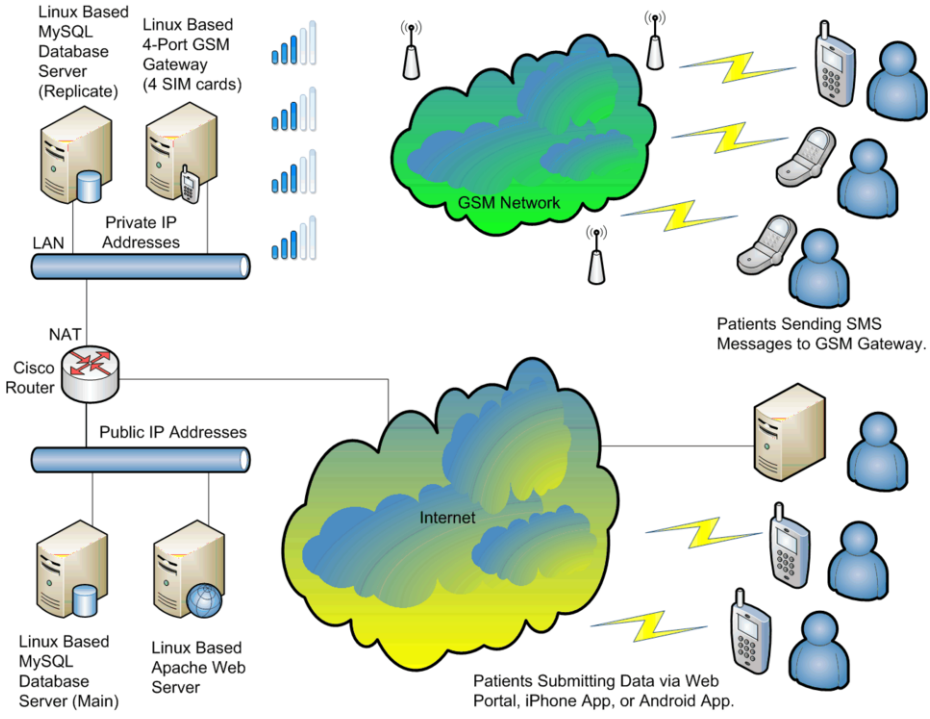

Figure 1. System architecture.

3.2. Database Design

The database forms an integral part of the system. All information received from doctors and patients, via any input mode, will be stored in a single database. It is the same database from which reports are generated. An efficient database design is critical as all other systems, such as the web portal, SMS gateways and the iPhone and Android apps are all built around this database.

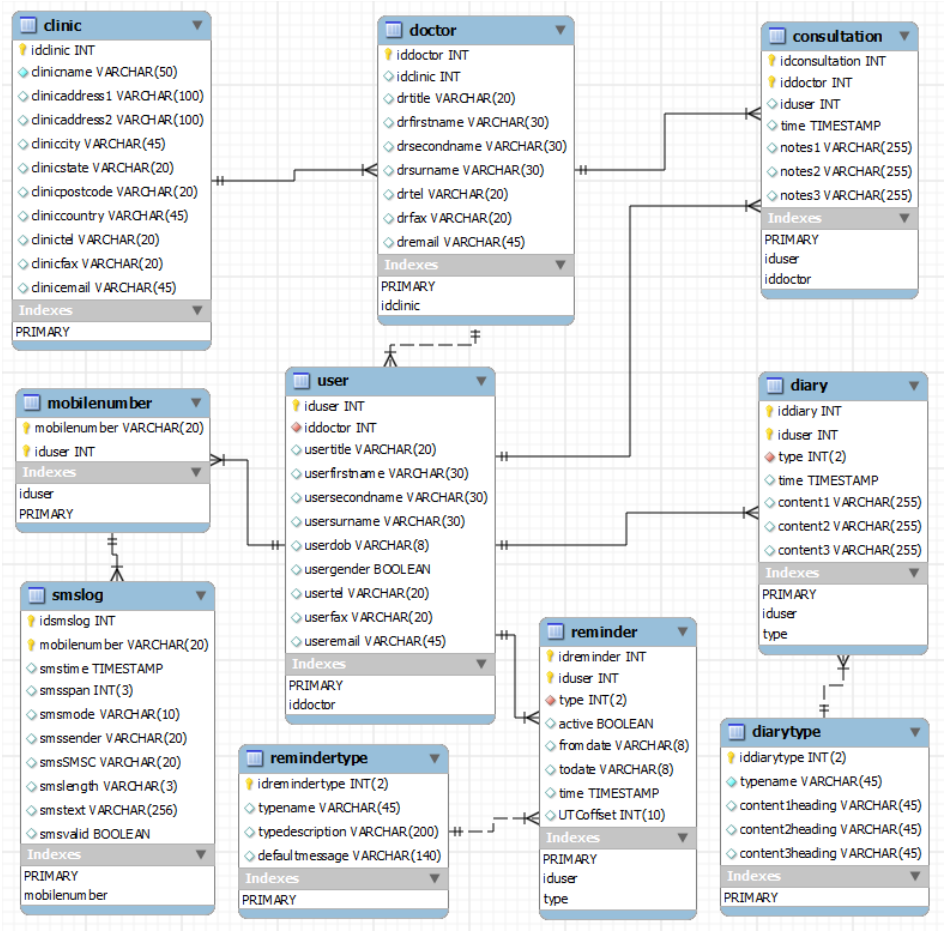

Figure 2. Enhanced entity-relationship (EER) model.

The high level database modelling is shown as an EER diagram in Figure 2. The database supports the following:

- the optional input of private information from patients, doctors and/or clinics
- input of blood glucose and/or insulin dosage levels captured through SMS or the website. This information is received on a regular basis.
- the recording of additional information, such as medication, diet, and exercise notes
- the input of consultation notes by healthcare professionals
- reminders if blood glucose and/or insulin dosage data is not received (see Figure 3)
- reminders for medication and/or insulin injections (see Figure 3).

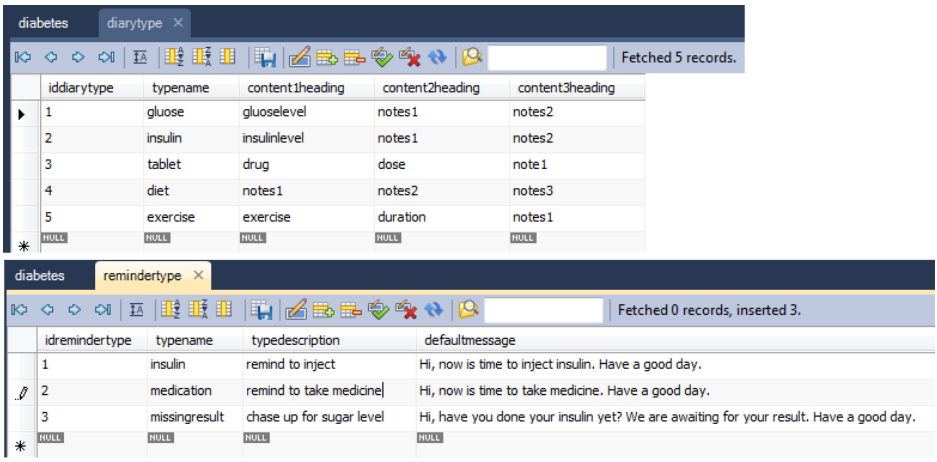

Figure 3. Database tables: diarytype and remindertype.

Figure 3 shows how diary types and reminder types are defined as look up table entries. This design allows for the addition of new types of diary entries and reminders without modifying the database structure.

4. Discussion and Conclusion

We have presented the ongoing development of a community-based self-management system for diabetes mellitus. The system can be used by a range of organisations including hospitals, universities, private clinics and healthcare groups, and is designed in such a way that allows for collaboration and involvement with other organizations. This may include adding SMS gateways in other countries and evaluation of the system by other research groups. Data collected will first and foremost be used for the benefit of patients on an individual level. However, from a public health perspective, a community approach allows for the collection of data from a large sample size, which

may be useful for future statistical analysis. For example, comparison of diabetic control between different ethnic groups, examining long term trends in diabetes management or finding correlation with other medical conditions may be possible.

The provision of personal information by patients will initially be optional. There are different regulatory measures which need to be considered in regards to privacy and patient confidentiality, which differs amongst jurisdictions. The aim of the personal information collected is not to identify patients; however, demographic information of patients will provide useful insight for various research and epidemiological purposes.

Future work will be necessary following deployment of the system for future development. Other data input modes, including iPhone and Android applications, need to be developed. Links to social media such as Facebook may be useful in providing a support network. Other considerations need to be made, such as refining the collection of data and demographic information.

This system embodies a relatively new telehealth approach, which involves patients sending measurements to a centralized database through SMS, in a standard format, which is then processed and analysed. Associated functions include the potential to send reminders or messages according to user-defined preferences. We envision that a similar approach may be useful for other health purposes, such as regular blood pressure measurements in the monitoring of hypertension.

Effective telehealth solutions will play an increasingly pertinent role in health systems worldwide. This paper has presented the development of a large scale, community-based self-management system for diabetes mellitus; the potential of such a system has been supported in literature.

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