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Tele-Healthcare for Diabetes Management: A Low Cost Automatic Approach

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Abstract — **In this paper, a telemedicine system for managing diabetic patients with better care is presented. The system is an end to end solution which relies on the integration of front end (patient unit) and backend web server. A key feature of the system developed is the very low cost automated approach. The front-end of the system is capable of reading glucose measurements from any glucose meter and sending them automatically via existing networks to the back-end server. The back-end is designed and developed using n-tier web client architecture based on model-view-controller design pattern using open source technology, a cost effective solution. The back-end helps the health-care provider with data analysis; data visualization and decision support, and allows them to send feedback and therapeutic advice to patients from anywhere using a browser enabled device.**

This system will be evaluated during the trials which will be conducted in collaboration with a local hospital in phased manner.

Index terms: Tele-healthcare, Low cost, Diabetes, Glucose, Automated

1. INTRODUCTION

Diabetes is a chronic disease that is on the increase worldwide at an alarming rate; according to the latest IDF's Diabetes Atlas [1]:

- Diabetes affects 366 million people worldwide and this number is expected to rise to 552 million by 2030.
- Type-1diabetes is rising at a rate of 3% per year and it is estimated that some 78,000 children aged 14 and under develop Type 1 diabetes annually.
- 80% of all diabetes cases are in low and middle-income countries.

Diabetes related complications such as retinopathy, neuropathy and nephropathy result in significant morbidity and mortality costing health services huge levels of expenditure. It was estimated that in 2007 the world spent in excess of $232billion for the treatment and prevention of complications; this cost is estimated to rise to $302.5 billion by 2025. Maintaining blood glucose as close to normal as possible significantly reduces the risk of long-term diabetic complications. This is the goal of diabetes management and strategies to assist in optimising diabetic control would therefore be highly beneficial and cost-effective.

One of the forms of the diabetes mellitus is type 1 diabetes (also referred to as Insulin Dependent Diabetes Mellitus)[2]. Type 1 diabetic patients have to perform a strict daily self-monitoring of their Blood Glucose Level (BGL) by measuring it before every insulin injection. They record their glucose measurements and insulin intake on hand written diaries, with additional information about diet, insulin intake and exercise. Every 2–4 months the patient undergoes periodical control visit, during which HbA1c (Glycated haemoglobin) laboratory results and diary recordings are considered by the diabetic team. This assesses the metabolic control achieved by the patients and updates their therapeutic insulin intake along with dietary and exercise advice. The drawback with this kind of monitoring and care occurs when the patient fails to monitor their blood glucose on a daily basis and inject the proper doses of insulin. This leads to poor control of their blood glucose level. The other issue with this kind of monitoring is that the health-care provider gets this information only when the patient visits the diabetic clinic for heir routine check-up usually after 2-3 months. These appointments can be irregular, inconvenient and results in poor communication.

Researchers have tried to address these problems by proposing different remote monitoring solutions. The work carried by Shea [3]on patients with diabetes mellitus showed that telemedicine case management improved glycaemia control]. McMahon et al. [43] have described a Web-based care management system for patients with poorly controlled diabetes. While investigating modem transmission of glucose values Chase et al [5] determined that fortnightly electronic transmission of blood glucose levels and other data in place of clinic visits resulted in similar levels of glucose control and similar rates of diabetes control when compared with standard care. In order to facilitate decision-making to health care providers Roudsani [6] presented a web-based diabetes management system (DiabNet) . In examining the security requirement for communication of patient records to remote management systems, Nigrin and Kohane [7] describe a prototype system that allows patients with diabetes to transmit self monitored blood glucose data from their glucometer device directly to their care provider over the internet. Farmer et al [8] have described a mobile phone-based telemedicine system for management of type 1 diabetes. This system was implemented on a Motorola T720i phone and a One Touch Ultra® blood glucose meter.

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However none of the reported works have been demonstrated consistently to improve clinical outcomes and that is why telemedicine has not been widely adopted in healthcare provision. Modern communications technologies and miniaturisation of electronic components offer considerable scope to refine and develop the concept of telemedicine into a clinically useful tool where the technology is used to monitor chronic conditions, offer decision support, and empower patients with the aim of improving their health outcome and quality of life and also reduce the spiraling costs for health service providers. It is postulated that in such technology enabled strategies low cost for both patient and health service provider is a key driver. Also, a key aspect of this type of technology is that it must require minimal work by the patient and clinician in order to be effective but must overcome the perception of a "Big Brother" style loss of privacy. It is also essential to understand what technological innovations may be acceptable by both patients and health service provider and how broadly they may or may not be embraced. These issues in our opinion are crucial to the translation of telemedicine into clinic in particular for chronic conditions such as Diabetes. In this context, this work presents a case study of a smart telemedicine healthcare system (WithCare+) developed in a close collaboration between the University of Sheffield (Electronic Engineering and Psychology) and Sheffield Teaching Hospital targeted at type 1 diabetes management. The overall system is depicted in Figure1 and supports three different approaches to the front end; the selection of one or the other or in some cases a combination of or all of the front ends at the same time for particular patients, will depend on patient preference, clinician recommendation and intermediate management results.

In this paper, we focus on one of the approaches, namely the lowest cost solution adopted for the front end which is the Ethernet/http based solution. Such low cost solution is advocated on the basis that the majority of patients would already have access to a router/Internet and the cost of the front end) can be easily afforded by the healthcare provider. Automatic transmission with no interaction will help the patients engage more positively with their treatment strategies.

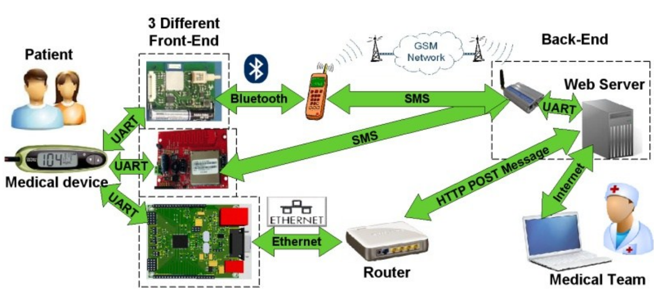

Figure 1. WithCare + System Overview.

2. THE SYSTEM

The system, as depicted in Figure 1 comprises a novel low cost front end electronic device and a back end server that work together in an intelligent way to support real-time communication between care provider and patient. The system is scalable, robust, and secure; it is optimized:

- To transmit readings (data) from medical sensors in a range of interfaces on a secure communication layer to the backend Server with little intervention from the patient.
- To provide the health care providers with 24/7 access to patient data in textual or graphical format for close monitoring.
- To report the episodes of hypoglycaemia and hyperglycaemia to all the members of the diabetic management team which could potentially save the life of the patient.
- To send automatic reminders to the patient if they fail to record their measurement within the specified time period in order to motivate them.
- To motivate patients to record their glucose measurement by improving the communication between all the stake holders of the diabetes team by integrating low cost existing solution to the system such as Skype, Facebook.
- To support continuous education of patients through Tele-consultation services.

The system has been designed and developed in consultation with the different stake players of the diabetic team namely, the Clinicians, Patients and Carers of the patients using software which is freely available; the front end for any browser enabled devices have been developed using php and business logic (i.e. analysis of incoming data) is handled using perl and mysql is chosen for the database. The application is deployed on an apache webserver and the system runs on Linux. The data from the different medical sensors could be transmitted to the server by sending an SMS or through http via the internet. The Server software takes care of different kinds of data by running in a multithreaded mode as daemon process to handle all the requests. Thus, implementing the system from a healthcare provider perspective would only need a Server machine or even just deployment in a cloud. From the patient perspective, once supplied with the cheap front end device, access to a router/Internet or possession of a wireless device (mobile phone) are the only requirements.

2.1 Front-end details

The main part of the Front-End in the Ethernet based solution is a very low cost single IC (W7100A) that integrates an 8-bit microcontroller with 64KB Flash, 64KB RAM memory and pre-built peripherals including multiple Timers, Watchdog, UART and importantly a hardwired TCP/IP stack (by WIZnet), MAC and PHY. The first proto-type was based on the WIZnet W7100A EVB development board Rev 1.1. From the software side the embedded projects were written C code developed in Keil uVision4 C51 v9.05 environment. The C application starts with initialization of the MCU hardware, UART, Timer, Watchdog Timer, and Ethernet and then allocates the required buffers for our specific functions, where data is read or sent from or to the UART device (glucose meter) and Ethernet. With additional API functions, the support could be extended to any serial port gluco-meter device. All tasks are managed by a simple polling approach and few interrupts for TCP/IP, UART, Timer0, INT0 button. This means that even this complex design was simplified to the extent that no RTOS was required for management of all tasks, as execution occurs in the defined time windows and interrupts priorities. The elimination of RTOS reduced the code size and hence, the code maintenance will be easy..

The Front-End as illustrated in figure 2 operates in the following manner. The Client plugs a gluco-meter into a suitable jack connector and presses the push button. The C API specific function detects the connected gluco-meter and begins the data collection of its pre-stored records which are then sent with POST request through port 80 to the Back-End Web Server for storage and analysis. If the data is delivered successfully then a Green LED will be switched ON otherwise a Red LED will be activated.

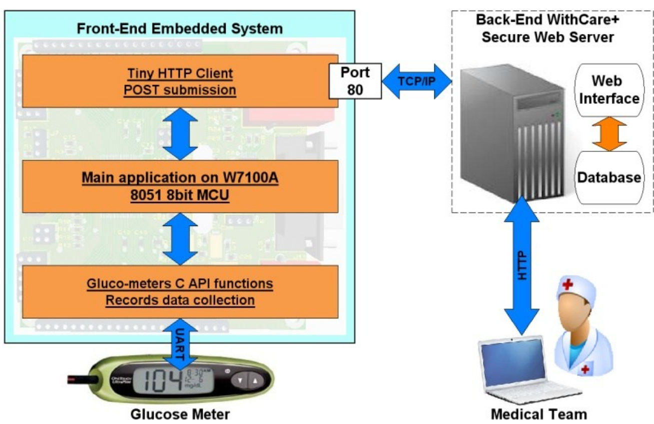

Figure 2. The Ethernet based Front-End Operation Flow.

2.2 Back end details

The high level architecture of the system showing the different components and the relation between components is illustrated in figure 3. The Backend is designed using model-view-controller design pattern which is popular for designing robust systems.[9,10] The application tiers of the system for remote glucose monitoring are shown and the interconnecting arrows indicate the data flow. The SmsHandler, multithreaded software module running a daemon process, reads text message from modem connected to server. SmsHandler analysis, updates and logs those messages to a temporary database. It also retrieves feedback from the database and transmits them to the patient's mobile phone. The HTTP post requests from patients are handled by the apache webserver using php and perl. A multithreaded software module, EventHandler, handles all the events from the patients and stores them temporarily in a database table.

The event handler is a software module which acts like the nervous system of the system. EventHandler reads the messages from the temporary database table and analysis the messages based on the designed business rules and extracts the readings of the patient from the SMS or post request. The readings are stored in a readings table of the database. If there are any alarming conditions such as low, high reading the event handler generates an alarm in the inbox of the clinician. The event handler also generates the alarm if the patient does not send the readings within the prescribed time and alerts the clinician. The event handler also keeps track of the health of system using automatic diagnostic of the modem and raises an alert for the system administrator which could reduce the downtime of the system. System administrator could easily configure from the user interface, how often the diagnostics should be run.

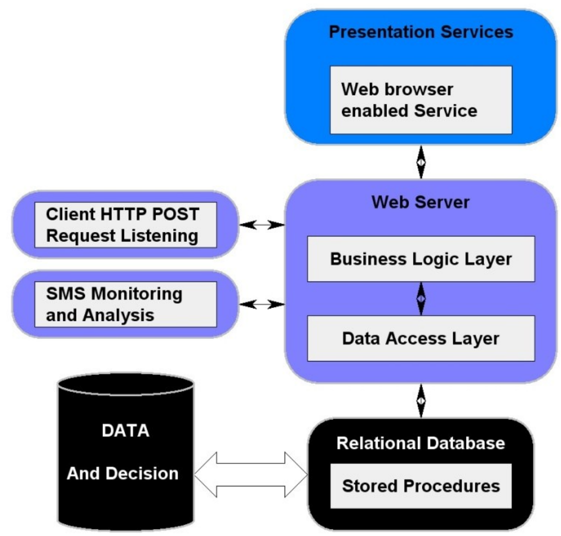

Figure 3. High Level Architecture of Backend Server

The diabetic team could keep track of the patients records on any browser enabled device which increases the mobility of the Clinician and translates the concept of 24/7 into action. However, the security measures implemented using mysql stored procedures make sure only authorized members of the diabetic team could access records of a particular patient. The presentation services layer is accessed by web browsers and makes calls to the business logic layer. The business logic layer then directly calls the data access layer, which then forwards requests for data to the database tier. To avoid possible SQL injection attacks, all requests for data from the database are executed by parameterized stored procedures. A type-safe generic collection of entity classes which map to the tables in the database are used to pass data across layers up to the UI consumer. The front end always communicates with the data access layer only through business logic layer which is useful for security, scalability and robustness of the system. It also makes system easy to manage. The clinician could register new patient, update existing or delete if needed. The clinician could view the records of patient both in tabular form and in graphical form. The graphs are generated in time series format and time duration could be selected by the Clinician. The graphs show the data in a scatter plot between time and the reading value. Any highs or lows are classified. A regression line with other descriptor statistics gives the clinician quickly a good idea of how the patient is performing over the period of time.

Skype, Facebook, SMS, and email have been integrated to the system for sending feedback to the patient by any member of the diabetic team.

Incoming readings are analysed and prioritized and those patients requiring attention due to high or low or no-glucose readings are highlighted first on a list of events to be actioned as illustrated in Figure 4.

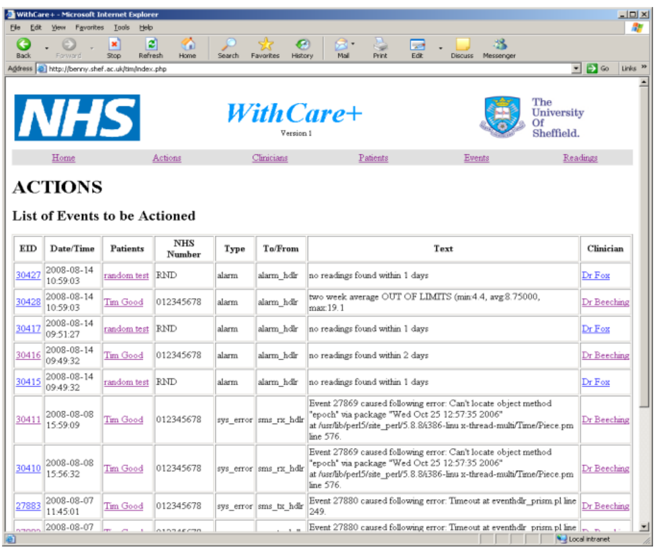

Figure 4. Snap shot of WithCare+ Back end Server showing prioritised cases that the Clinician need to address first (low, High or no readings)

3. CONCLUSIONS

In this paper, a tele-healthcare system for improving the management of glucose level of insulin dependent diabetic patients has been presented. The system is an end to end low cost automated solution which relies on transmitting patient's glucose readings in real-time automatically and securely using a dedicated front end (patient unit) device to an intelligent back end that analyses the data and presents it in a meaningful form to the clinicians allowing them to target care in a more efficient and productive way in terms of quicker response to urgent cases, better focus on difficult non-engaging non-adherent to treatment patients, and behavioural changing feedback. A key feature of the system developed is the very low cost automated approach adopted that will help translate the technology into a clinical tool.

The system will be evaluated during the trials which will be conducted in collaboration with Sheffield's Children hospital in a phased manner starting this summer. The evaluation of the system will be done to substantiate the hypothesis that the use of a low cost automated tele-healthcare system could present an advantage in the management of insulin dependent diabetic patients, by improving their quality of life and ultimately their clinical outcome measured in terms of at least 0.5% improvement in their HbA1c. Cost effectiveness of the interevention from the health service provider perspective (NHS) would also be evaluated.

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REFERENCES

[1] http://www.idf.org/diabetesatlas/news/fifth-edition-release

[2] D. R. Hanas, *Type 1 Diabetes*, second ed.: Class Publishing,Barb House,Barb Mews,London W6 7PA,Uk, 2004.

[3] S. Shea, J. Starren, R. S. Weinstock, P. E. Knudson, J. Teresi, D. Holmes, W. Palmas, L. Field, R. Goland, C. Tuck, G. Hripcsak, L. Capps, and D. Liss, "Columbia University's Informatics for Diabetes Education and Telemedicine (IDEATel) Project," *Journal of the American Medical Informatics Association,* vol. 9, pp. 49-62, January 1, 2002 2002.

[4] G. T. McMahon, H. E. Gomes, S. Hickson Hohne, T. M.-J. Hu, B. A. Levine, and P. R. Conlin, "Web-Based Care Management in Patients With Poorly Controlled Diabetes," *Diabetes Care,* vol. 28, pp. 1624-1629, July 1, 2005 2005.

[5] H. P. Chase, J. A. Pearson, C. Wightman, M. D. Roberts, A. D. Oderberg, and S. K. Garg, "Modem Transmission of Glucose Values Reduces the Costs and Need for Clinic Visits," *Diabetes Care,* vol. 26, pp. 1475-1479, May 1, 2003.

[6] N. Zhao, A. Roudsari, and E. Carson, "MED31/437: A Web-based Diabetes Management System: DiabNet," *J Med Internet Res,* vol. 1, p. e68, September 19 1999.

[7] D. J. Nigrin and I. S. Kohane, "Glucoweb: a case study of secure, remote biomonitoring and communication," *Proceedings / AMIA ... Annual Symposium. AMIA Symposium,* pp. 610-4, 2000.

[8] A. G. Farmer, Oliver2; Hayton, Paul2; Bryden, Kathryn1; Dudley, Christina3; Neil, Andrew3; Tarassenko, Lione, "A real-time, mobile phone-based telemedicine system to support young adults with type 1 diabetes," *Informatics in Primary Care,* vol. 13, pp. 171-178, 2005.

[9] A. Leff and J. T. Rayfield, "Web-application development using the model/view/controller design pattern," 2001, pp. 118-127.

[10] E. Gamma, *Design patterns: elements of reusable object-oriented software*: Addison-Wesley Professional, 1995.