How to Interact: Evaluating the Interface between Mobile Healthcare Systems and the Monitoring of Blood Sugar and Blood Pressure

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Abstract— **The availability of mobile healthcare systems is increasing in demand. The world's population today is faced with many health challenges all of which require the patient to be more empowered and monitor his own health. This research focuses on some of the mobile healthcare systems available for the monitoring of two chronic non-communicable diseases: diabetes and hypertension. The study investigates the usability of a new interface that is made available through existing healthcare monitors, one based on Bluetooth transmission. Seven Bluetooth-enabled systems used for measuring and recording blood sugar and blood pressure were selected and evaluated based on a set of user-centered heuristics. This paper focuses on the results of this evaluation. Two systems out of these were then chosen to undergo live user trials with a mobile application called myDR (short for my daily record). The objective of the trials was to confirm that the myDR integrated self-monitoring system was a more efficient and satisfactory method for the measurement and recording of blood sugar and blood pressure; therefore leading to faster adoption and sustainability. The results of the study indicate that the integrated system is more efficient and the preferred interface of the target user group, and that Bluetooth technology is an ideal candidate as the communications protocol for mobile healthcare applications.**

Index Terms— **Blood Pressure Meter, Blood Sugar Meter, Bluetooth, Diabetes, Hypertension, Mobile Healthcare, Self-Monitoring Devices.**

I. Introduction

Chronic non-communicable diseases account for almost 60% of all deaths worldwide. In 2005, a quarter of these deaths occurred in men and women below the age of 60. For example, in Trinidad and Tobago (the country ranked fifth highest in the world in terms of percentage of population living with diabetes), the major causes of deaths are attributable to non-communicable diseases. These are cardio-vascular disease 25.1%, diabetes 13%, cancer 13% and cerebrovascular disease 10.4%, totaling 61.5% [2]. Cardio-vascular disease and diabetes, in particular, are major non-communicable diseases in the Caribbean region.

Many systems have been developed to address the need for proper self monitoring and recording through the use of mobile phones [8, 9]. However, not much research has been conducted to determine the efficiency and perceived usefulness of these types of systems. In this paper, the term system refers to the meter that is used to measure blood pressure (BP) or blood sugar (BS); the terminal used to store the readings (i.e. PC or mobile device) and the means of transferring the results from the meter to the terminal.

This study concentrates on mobile telephony as a healthcare platform. [10] explains that mobile phones have four characteristics that make them suitable as a new health care platform: personal, ubiquitous, connected and increasingly intelligent. Since each phone is associated with a person, applications can be customized and personalized to suit. Mobile users can also monitor their health on the go, anywhere and anytime. Furthermore, the mobile phone allows the user to stay in touch with different sources of health care e.g., caregivers, doctors etc. Lastly, the processing power of mobile phones continues to grow and therefore complex processing of health data is now possible on these small devices.

The usability of these types of systems is of utmost importance because it dictates their success of the adoption and sustainability, thereby improving the self-care practices on the part of the user. Furthermore, when it comes to medical devices there is a certain stigma attached to them. Many patients consider healthcare to be a private matter and do not wish to use systems that may draw 'too much attention' to them and would prefer to keep their medical monitoring and recording personal.

II. Existing Research

This study is one of the inputs into the design and development of the Caribbean-wide Healthcare Management System called MediNet [1] currently being developed by researchers at The University of the West Indies.

One of the main challenges of using mobile devices is the restrictive data entry methods [4]. The small buttons, screens, fonts etc. on mobile devices make the process of data entry

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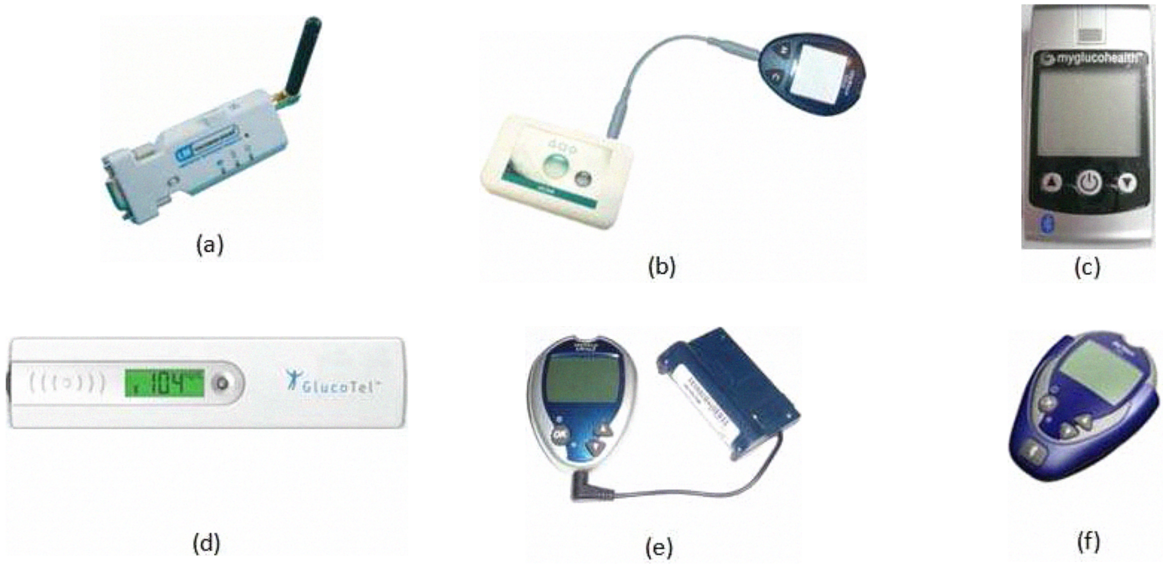

Fig. 1. Bluetooth-Enabled Glucometers: (a) Home-made solution (b) eLink (c) Entra Health (d) BodyTel (e) PolyMap and (f) t++ Cradle

challenging. It strongly impacts on the effectiveness and efficiency in entering data, which influence the speed and accuracy of performing data entry tasks [7].

Researchers [5, 6] have investigated the effectiveness and efficiency of various data entry techniques that aid users in entering data into a mobile device. Each of these methods has advantages and disadvantages. For example, voice recognition helps users with physical disabilities but presently produces high error rates. Soft keyboard has been shown to be more accurate in comparison to other input methods but it is not convenient when the user is in motion. Therefore, the selection of data entry technique will depend on the context in which the system will be used.

This study focuses on the communication interfaces that automatically transfer the readings to a data access point without the need for data entry on the part of the user. Research [19] has shown that there are three popular communication protocols with existing healthcare systems including: USB, RS-232 and Bluetooth. Some vendors of healthcare meters provide USB port on their healthcare meters. These USB ports offer slave connectivity. This makes them only compatible with a PC USB port. Therefore USB-enabled healthcare monitors are not suitable for healthcare monitoring systems that use a mobile phone as the data access point. Hardware implementation of RS-232 is simple; therefore some vendors provide RS-232 connectivity with their healthcare meters. However, mobile phones available in the market do not contain RS-232 ports. Hence this option is not suitable for healthcare monitoring systems based on mobile telephony. Being a short-range and low-power communication protocol, Bluetooth is being used by some vendors of healthcare meters for communication between the monitors and PC or mobile phone. Since Bluetooth is also very popular in mobile phone communication, it becomes an ideal candidate for transferring readings from the healthcare monitor to the mobile phone. Moreover Bluetooth is proven to have high data transfer rates, surpassing serial and parallel ports. Therefore, in our research we only examined healthcare systems that used the Bluetooth protocol for communication between the mobile phone and the measuring devices.

Over the past ten years, there has been a radical shift from wired to wireless medical devices which has promoted the design of systems that are less intrusive. Bluetooth is the most recent wireless protocol in the medical domain. As a low-power, point-to-point protocol with an accepted IEEE standard, Bluetooth facilitates increased patient mobility since patients do not have to be tethered to the measuring devices. For these reasons, only Bluetooth-enabled medical devices were considered in our research. Furthermore, from an HCI perspective, the use of Bluetooth technology as a means of automatically transferring the meter reading reduces the user's task load.

III. Available Bluetooth-Enabled Measurement Devices

The meters described in this section represent the ones that were available at the time of this research. In some cases the healthcare meter acts as the master in the Bluetooth transfer and in other cases the meter acts as the slave. This influences the design of the client application that receives the reading which is discussed in more detail in the following sections.

A. Blood Glucose Meters

A blood glucose meter (or glucometer) is a medical device for determining the approximate concentration of glucose in the blood. Blood glucose is measured in mg/dl (milligrams of glucose per deciliter of blood) or mmol/l (millimoles/liter). The normal blood glucose level is about 90mg/dl or 5 mmol/1. This section describes some of the popular Bluetooth-enabled glucometer systems – Figure 1.

There are two types of systems: (1) fully integrated solutions that comprise the glucometer and Bluetooth feature

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(a) (b)

Fig. 2. Bluetooth-Enabled Blood Pressure Measurement Devices: (a) Omron BP Meter and (b) A&D BP Meter

all in one and (2) Bluetooth adapters that work in conjunction with an existing glucometer. The One Touch Ultra2 glucometer from LifeScan is popular with the latter option mainly because of the availability of its communication protocol.

Home-made solution: Final Year Student Project at University of Birmingham

In this system, an LM Technologies Bluetooth RS-232 Adapter is used to transfer readings from a One Touch Ultra 2 blood glucose meter to a Smartphone (Vodafone V1240) running Windows Mobile 5.0 for Smartphone via Bluetooth. A cable is needed to connect this adapter to the OneTouch Ultra2 glucometer. An antenna from the adapter transmits the Bluetooth signals to the Smartphone. This system was not available on the market at the time of this research, therefore was excluded from the heuristic evaluation described in the Section IV.

eLink Adapter by eHIT Limited

The eLink Adapter can be used to convert the communication from a measuring device to a Bluetooth Serial Port Profile (SPP) communication. For serial transmission, the eLink Adapter must be connected to the measuring device with a serial cable. Once communication with the adapter is achieved, device specific protocols must be used to obtain the readings from the measuring device. The eLink Adapter is able to provide the same functionality as the LM Technologies Bluetooth RS-232 Adapter; however, it is more flexible and can be used with any measuring device which transmits via serial or infrared communication.

Entra Health Systems: myGlucoHealth

This blood glucose meter integrates the Bluetooth module with the measuring device in one unit. Users must start up an application on their mobile device and then push a button on the meter, which activates the Bluetooth, to transfer the readings. Here the Bluetooth module on the device is acting as a slave. The device resembles a cell phone with the intent to draw less attention from other persons (who might think it is a cell phone rather than a glucometer).

BodyTel: GlucoTel

The GlucoTel meter from BodyTel, like the myGlucoHealth blood glucose meter, integrates the Bluetooth module with the measuring device in one unit. It is much smaller and does not look very conspicuous but it does not have the appearance of a standard glucometer. The Bluetooth module on the meter acts as a master. Thus, the application on the mobile phone must wait until the readings are transferred from the meter; initiated by pressing a button.

PolyMap Glucose Meter Accessory (GMA)

This product is designed for use with a One Touch Ultra2 meter. It is similar to the t+ Medical cradle (described in the next section) in functionality except that a short 6-inch cable, attached to the adapter, is used to connect to the meter. The Bluetooth module on the device is a master so this requires the application on the mobile phone to wait until the device is ready to transfer the readings. After the testing strip is inserted into the meter and taken out, the Bluetooth is activated and the readings are automatically transferred to the mobile phone (or other access point). The device then powers itself down.

t+ Medical Cradle

The Bluetooth cradle from t+ Medical is meant to be used with a One Touch Ultra 2 blood glucose meter. It uses a stereo jack which is one inch in length, to connect to the One Touch Ultra2 meter which fits snugly inside the cradle. The Bluetooth module is located at the back of the cradle which uses its own power. This device acts as a Bluetooth slave so the application on the mobile phone controls the transfer of the readings. Similar to the device from Entra Health Systems, the application must be started up on the mobile phone and then a button must be pressed on the cradle to activate the Bluetooth. An option on the mobile application must then be selected to initiate the Bluetooth transfer. Like the PolyMap GMA, the One Touch Ultra2 communication protocol has been integrated into the protocol of the cradle.

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B. Blood Pressure Meters

A blood pressure meter is a device used to measure blood pressure, comprising an inflatable cuff to restrict blood flow, and a mercury or mechanical manometer to measure the pressure. The blood pressure reading is broken up into three components: the systolic pressure, the diastolic pressure and the pulse rate. Bluetooth-enabled blood pressure meters were not very common at the time of this research. However, we were able to source and experiment with two Bluetooth-enabled blood pressure meters for our research: A & D UA-767PBT Blood Pressure Meter and Corscience Promedia Omron 710IT Blood Pressure Meter.

A & D UA-767PBT Blood Pressure Meter

This meter acts as a Bluetooth master in the transfer of readings from the device to the mobile phone. The device has one large button to interface with users. When the button is pressed, the readings are taken and then displayed on its monitor. After displaying the reading to the user the device transmits the readings to the mobile phone via Bluetooth. It uses a very similar protocol to the PolyMap GMA discussed before.

Corscience Promedia Omron 710IT Blood Pressure Meter

This device is an Omron blood pressure monitor to which a Bluetooth module has been added to transfer the readings to another Bluetooth-enabled device. It has more capabilities than the A&D meter. For example, it can act as a slave for device configuration or as a master when transferring the readings to a Bluetooth access point. The meter has several buttons on its interface which provides different control features to the user. This meter also comes with its own protocol to link the device to a mobile phone.

IV. Heuristic Evaluation

[3] discusses seven user-centered principles to be followed when designing new interfaces. We used these guidelines to evaluate the meters mentioned in Section III and selected the best candidates for live user trials. A summary of this evaluation is provided in this section along with the selected meters for the user trials.

Two other aspects influence the weighting of each meter's selection score: ease of system integration and availability of the meter in market. The former refers to how easy it is for a developer to integrate the healthcare meter with a mobile phone application, and the latter places emphasis on the fact that there is a higher probability that people will use systems with which they are familiar.

A. Evaluation Criteria

Principle 1: Use both knowledge in the world & knowledge in the head

The t+ cradle, A&D and Omron meters scored high on this criterion. In the case of the cradle, the design is quite intuitive on how to attach the meter to the Bluetooth component as it resembles a casing/cradle for that type of meter. The A&D and Omron meters both resemble the market standard blood pressure meter, with similar operations. Therefore, the user is not aware of the added Bluetooth component as the devices operate as usual. The eLink, Bodytel and PolyMap meters are fairly new designs, so no recall is possible on the part of the user and the BodyTel device resembles a thermometer, while the Entra Health device resembles a phone.

Principle 2: Simplify the structure of tasks

The Bodytel, PolyMap, t+ cradle and A&D meter scored high on this criterion. Both the Bodytel and A&D devices offer a full integrated solution, there is no need for an additional accessory and one button on the devices activates the transfer of readings. In the case of the PolyMap accessory, the removal of the testing strip activates the Bluetooth transfer. Therefore the user need not perform an additional step to activate the transfer. A separate serial cable is required to attach the eLink adapter to the OneTouch that does not come with the device. There are three buttons on the meter: one to turn it on and off, two buttons to navigate through the device. One of these buttons also activates the transferring of the measurements when pressed in the 'off' state. This button is labeled with the Bluetooth symbol. The Omron meter has five buttons on the device. One button is used to start the device; which also acts as a mode switch when pressed for long. Another is used to start the measuring process and two buttons are used to adjust the settings. The fifth button is used to navigate through the old readings on the meter.

Principle 3: Make things simple: bridge the gulfs of execution & evaluation

All the devices except the eLink and Omron devices ranked high in this area, for many of the same reasons listed in Principle 2. Because there are many controls on the devices, it is difficult to determine the function of each control without the use of the manual.

Principle 4: Get the mappings right

The PolyMap, t+ cradle and A&D devices scored high on this criterion. The designs of the devices are intuitive and the user is able to operate each fairly easily. The PolyMap cable fits into the only available port on the meter. The button to activate the Bluetooth transfer on the t+ cradle is very prominent and the glucometer can fit only one way into the cradle. The A&D meter only has one button which is large and blue. The buttons on the eLink device do not have the mapping of regular buttons; they are represented with a flat circular surface. The Entra Health device resembles a phone but does not have any of the phone-like features so this may mislead the user.

Principle 5: Exploit the power of constraints both natural and artificial

The scores were similar to Principle 4, with the same reasons being applicable here. In the case of the Entra Health

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(a) (b)

Fig. 3. myDR Application (a) on the Nokia 5310 and (b) on the HTC Touch

device the user cannot activate the Bluetooth transfer in the 'on' state. The button in this state acts as a navigational control. Here different functions are associated with the same button.

Principle 6: Design for error

Most of the devices scored the same for this criterion. Error messages are provided on the screen display. However, the error messages are colour coded on the eLink adapter, with different combinations having different meanings. This increases the memory load on the part of the user as it is difficult to diagnose the problem.

Principle 7: When all else fails, standardize

Even though the eLink, PolyMap and t+ cradle are new accessories, they all use a well established meter on the market. The A&D and Omron meters both conform to the standard blood pressure meter. The BodyTel and Entra Health are new glucometer designs and do not resemble the typical glucometer.

System Integration

All the devices that use the LifeScan OneTouch meter scored high here because the meter's protocol was publicly available and therefore integration with a mobile application was possible. The A&D meter's protocol was also very similar to the OneTouch.

Availability in Market

The PolyMap, t+ cradle, A&D and Omron devices scored high on this criterion. With the PolyMap and t+ cradle, the associating meter is widely available, along with test strips, lancets etc. However, the accessory itself is available from the vendor; which in the case of t+ cradle was only accessible in certain markets.

B. *Selected Meters*

The OneTouch Ultra2 with PolyMap Glucose Meter Accessory and the A& D UA-767PBT Blood Pressure Meter were selected based on the heuristic evaluation. Both devices scored very high on a rating scheme applied to the guidelines. They ranked high in simplicity, ease of use, and the use of appropriate mappings and constraints in their design.

TABLE I
PATIENT PROFILE

Feature	Value
Diabetes	Type II
Age	45-70
Gender	4 males, 11 females
Owns Glucometer	6
Owns Blood Pressure Meter	6
Non-mobile Phone Users	3

Furthermore, they were also easily available on the market as were their protocols. The t+ cradle also ranked high but its availability was limited to certain markets. The following section describes the experimental design of the live user trials that were conducted with the selected meters.

V. Experimental Design

The aim of this usability study was to obtain some preliminary feedback on the usage of the selected devices and the integrated self-monitoring system for diabetic patients. The assumption is that this new type of system will be easier to use and help the patient keep better records of their physiological states and therefore maintain a healthier lifestyle. Furthermore, the Bluetooth interface will aid in the adoption of the new technology since it proposes to lessen the data entry load of the user by automatically transferring the values.

The three ISO 9241-11 usability measures under consideration were (1) efficiency of the system (2) the simplicity of the system and (3) user satisfaction, where efficiency was measured by the mean time taken to complete a task correctly, and simplicity and satisfaction were measured by questionnaires and participants' perception of the system.

A mobile-based application, called myDR [20], was designed for the use with the selected meters. The application was developed for two separate mobile phones to assess how the integrated solution worked on different platforms. A Java-based system was developed for a Nokia 5310 mobile phone using MIDP 2.1, and a C++ application was developed for the HTC Touch which runs Windows Mobile 6.0 - Figure 3. myDR allows the user to enter and record their readings obtained from the selected glucometer and blood pressure meter.

The participants were invited to the study based on a volunteer basis. At the start of the study the objectives and confidential nature of the study were explained and each participant signed a consent form. Two questionnaires were administered to the group at the beginning of the trial. The first questionnaire was used to gather information on the participant's current measuring and recording process (if any) and the second questionnaire was used to obtain information on the participant's mobile phone usage.

The testing group comprised 15 Type II diabetic patients. The patient profile is provided in Table 1. Each participant was also allowed to use the phones before the actual testing started to get familiar with their operations and navigational

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structure. The users were observed as they interacted with the system and all observations were recorded, including the time taken to complete a measurement task. After the study period was completed all participants were surveyed again; this time the aim was to obtain feedback on the system. The results and discussion are presented in the next section.

VI. Results And Discussion

The time taken to complete a measurement task was recorded and analyzed. The participants who had previous knowledge of healthcare meters finished in a faster time than those who did not, as expected. The overall comments from the participants supported the use of the new Bluetooth interface. 66.67% perceived the Bluetooth interface very easy to use. 93.33% perceived the automatic entry to be faster than their normal monitoring process and 73.33% preferred the automatic entry over their existing monitoring process. The other 26.67% had no preference.

The most popular reasons for preferring the Bluetooth interface were "less recording on the part of the patient" and "minimizes errors when recording."

One noticeable observation when conducting the trials was the possible interference from other devices that may occur during a Bluetooth transfer. In one case the Bluetooth BP meter was not transferring the values because there was another wireless device in the vicinity. Therefore these technical details must be taken into consideration when using this type of interface.

In the next stage of the project, the other components of the Caribbean-wide Healthcare Management System will be tested and in November 2009, clinical trials with 150-200 patients will begin to test the hypothesis that the system does improve the health status of a patient living with diabetes.

VII. Conclusion

When any new system is introduced into the market it is important to ensure that a user-centered design approach is followed. Good usability ensures that the new technology will experience a favorable adoption rate as well as a sustained usage. This study focused on different healthcare devices used to measure the BS and BP of patients. An heuristic evaluation was performed and the PolyMap Glucose Meter Accessory and the A& D UA-767PBT Blood Pressure Meter ranked the highest. The user trials confirmed that the Bluetooth interface is the preferred style for the target user group and shows a 73.33% preference to use. Future work will involve the enhancement of the myDR mobile phone healthcare application to meet the special needs of this type of user. Parameters such as health history, context and culture will be exploited to personalize the system. The objective is that through these surveys, trials and user-centered approaches the new system will be one that is easy to use, aids in the monitoring and recording process, and becomes an integral but non-intrusive part of the user's life.

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