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Data Acquisition in a Wireless Diabetic and Cardiac Monitoring System

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Abstract— **A telemedicine system is described for monitoring the vital signs and general health indicators of patients with cardiac and diabetic conditions. Telemetry from wireless sensors and readings from other instruments are combined into a comprehensive patient health dataset. The data can be stored, accessed and displayed using mobile Internet communications with a server. The paper concentrates on the data acquisition process, using an alternative sensor network protocol to Bluetooth and manual data entry into a smartphone application and HTML5 web browser.**

I. Introduction

Telemedicine is literally medicine from a distance and is synonymous with a telecommunications network for the transmission of medical information. The fundamental parts of such a system are the measuring devices (e.g. instruments or sensors), a device to format the readings for a communications link (e.g. patient smartphone or PC), a clinic server to which the data are transmitted and a device to display the data obtained from the server (e.g. clinician smartphone or PC).

Since this technology has been an active research area for at least twenty years, and many systems have been implemented for both research and commercial use, our UK-India Education and Research Initiative (UKIERI) project [1] has a remit of building on this previous work and the existing mobile telecommunications network. For this project, a telemedicine system has been implemented specifically to improve the monitoring of cardiac and diabetic conditions within the UK and India; the components of the system are now in place, technical trials are underway and clinical trials will follow.

This paper highlights the project's efforts to improve the monitoring of cardiac and diabetic conditions by building on previous work described in the literature. In particular we investigated alternative wireless node components, how to ease the method of data acquisition and incorporate information from standard instruments, and how to enable participation with a standard HTML5 web browser.

The remainder of this paper is structured as follows: section II details the general system architecture, section III deals with the patient wireless nodes and transmission protocols and section IV with how a smartphone is used within the system using an application and web browser.

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II. System Architecture

The system architecture used in the project follows the generic arrangement for a telemedicine system and is shown in Fig.1. The patient monitoring system includes the wireless medical sensor nodes, a mobile device (smartphone) and other medical instruments without a communication capability. An Internet link over Wi-Fi or 3G connects the patient smartphone to the server and database location. Other users can access the medical data on a PC or smartphone using a web browser. The server and database platform used to store the patient measurements uses Apache server software, PHP scripting and a MySQL database. The server and database are situated in the UK and can readily be accessed by the project partners in India over an Internet link.

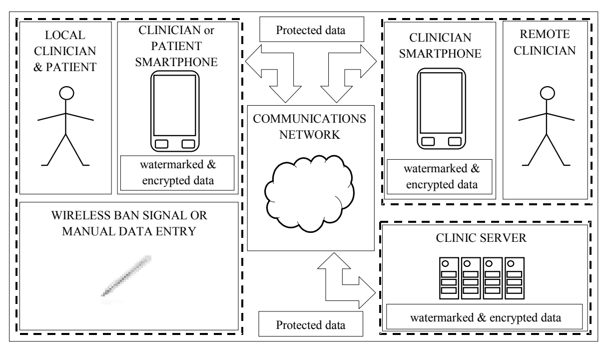

Fig. 1. Schematic of the telemedicine system architecture. A patient transmits wireless or manually entered data to the server via an Internet link. The data is downloaded by a patient or clinician using an HTML5 web browser.

The system was designed to acquire readings from both wireless nodes and standard instruments, as, although many measurements such as temperature, respiration and ECG lend themselves to be acquired electronically with no invasive procedure, the measurement of blood sugar is still largely performed directly from blood samples. Although some blood sugar instruments have wireless capabilities, most do not, and blood sugar monitoring is a good example where wired instruments still need to be included in the patient's monitoring system. In our implementation, a LifeScan OneTouch Ultra 2 [2] glucose meter was used in the evaluation and allowed the patient to simply read the instrument's display and record the value on the smartphone.

The sensor nodes are to be worn by the patient and are arranged as multiple slaves accessed by a single master with node communications taking place through wireless transceivers. The master node has a similar configuration to the slave nodes, but has the addition of a Bluetooth transceiver to link to the smartphone. Since Bluetooth is available in all such mobile devices, this part of the telemetry link is largely predetermined. The wireless node body area network (BAN) link has more options, including Bluetooth, ZigBee and proprietary protocols.

In the current implementation, the nodes use an alternative proprietary Nordic 2.4 GHz low power with high data rate transceiver specifically designed for low-power, long battery life applications such as embedded solutions and medical sensors [3]. It allows one master node to communicate with a star network of up to six slave nodes.

To allow the user to acquire, store, upload, download and display medical readings from the patient and the server location, a telemedicine application was developed for the patient smartphone. As well as Bluetooth for the master node communication, the smartphone also has mobile phone and Wi-Fi capabilities for Internet access. Its Windows Mobile operating system has similar capabilities to a Java-based operating system on other comparable devices.

The web browser on a user's PC or smartphone cannot control the Bluetooth link, but the user can still acquire, upload, download and display medical readings using the system's web pages.

III. Wireless sensor nodes

The wireless slave and master nodes, apart from the addition of a Bluetooth transceiver on the master node, share a common design of power supply, signal acquisition, microcontroller and Nordic transceivers.

A. Slave nodes

These are to be worn by the patient and connected to the measurement transducer using a wired link. To contribute to a prolonged node battery life, the node's microcontroller unit (MCU) is the ultra-low-power MSP430F2618E mixed signal device from Texas Instruments [4], a 16 MHz 16-bit RISC device with a 12-bit ADC, four universal serial communication interfaces (USCI) and direct memory access (DMA) controller. Three slave nodes have been developed to measure ECG, temperature and respiration respectively. A fourth node, to acquire the signals for wrist pulse analysis of a patient, is currently under development and uses non-invasive pressure sensors to measure pressure over the radial artery of both wrists to obtain data suitable for the Indian Ayurveda system for health state diagnosis [5].

The transducer's signal is taken through an analogue signal conditioning stage and then to the ADC of the MCU. The MCU's DMA facility allows the fast transfer of data between memory addresses and this is used in the digital filtering stage. The ADC output is filtered with the digital filter and formatted values sent to the Nordic transceiver by serial peripheral interface (SPI) link. The Nordic transceiver sends the data wirelessly to the master node.

B. Master node

The master node is also worn by the patient and has the same design as the slave nodes apart from a Bluetooth transceiver for smartphone communications. The master Nordic transceiver listens for incoming data from the slave nodes as each slave is polled by the master. The incoming data is read from the Nordic transceiver by the MCU on a USCI port and formatted data is sent to the Bluetooth transceiver on a second USCI port.

The Bluetooth transceiver is a KC Wirefree KC-21 device [6] supporting the Bluetooth serial port profile (SPP) and driven by modem AT (attention) commands from the MCU [7]. Once the master node is Bluetooth paired with the patient smartphone, the smartphone initiates a connection by opening its virtual serial port to the node and communications can begin

C. Node network transceiver

Two important considerations in the selection of a suitable BAN transceiver were physical dimensions and the node's battery life. The Nordic transceivers were found to be particularly well suited in these respects as they operate in the international ISM 2.4 GHz band, this being a common option for such applications. Operation in this band can be achieved using small antennas that can enable the complete unit to be built to a practical size suitable for placing on the body.

An obvious feature of a wearable node is that the antenna will be in close proximity to the body of the patient and many studies, including [8] and [9], have shown that the signal losses between nodes increase as the antenna gets closer to the body, due to absorption through the body and path loss around the body. To mitigate these losses, one option is to increase the transceiver's output power at the risk of reduced battery life and increased localised radiation absorption. A second option is to use the medium access control (MAC) protocol so that the transceiver is only powered when necessary.

The latter option has generated research into the design of the node network topology and also the MAC protocols. Some solutions proposed include sending node data directly to a master node (single hop) [10] and nodes retransmitting data received from other nodes (multi-hop) [11]. Such strategies are designed to allow the nodes to operate on reduced power for most of the time to conserve battery life, but still use low power transmissions when necessary.

The options for 2.4 GHz transceiver devices with suitable MACs include Bluetooth low energy technology [12], ZigBee [13][14], ShockBurst [15] and ANT [16]. Classic Bluetooth has also been used in BANs, such as in [17], although it is not targeted at small battery cell applications. Low energy Bluetooth devices were not available at the time design decisions were made for this project. An overview of wireless technologies used in medical monitoring is in [18].

The nodes selected for use in the current project use the nRF24L01 ShockBurst transceivers from Nordic Semiconductor [3]. These permit transmission at a higher bit rate than ZigBee (up to 2 Mbps rather than the 250 kbps of ZigBee), the MAC protocol is simple to implement and six nodes are adequate for the current project and multi-hop is not required. The ShockBurst network topology consists of a 6-point star with the master node at the centre of the slave nodes. The master node communicates through 'data pipes' which are assigned unique addresses. By setting a slave node to the same address as a data pipe, the master can then communicate with that node. To help mitigate data collisions between similar nodes nearby, each node in a particular network is configured to use a unique frequency channel from the 83 available between 2.4-2.4835 GHz.

The MAC protocol also has an automatic data packet assembly and an auto-repeat function for lost packets. Each packet consists of 1 byte of preamble, 3 to 5 bytes holding the pipe address, up to 32 bytes of payload and 2 bytes for a checksum value. After a slave node transmits a packet it listens for an acknowledgement from the master node. If the acknowledgement isn't received the packet is retransmitted. The transceiver transmits new data as soon as its controlling MCU instructs that it do so; the delivery of the data is then left up to the transceiver, which can report back problems via registers. As soon as the master node receives a packet with a valid address, it tests the checksum, transmits an acknowledgment to the same address and stores the payload in a register for its controlling MCU to read.

D. Node Bluetooth transceiver

The Bluetooth link between the master node and patient smartphone implements a data exchange protocol using the SPP of the KC Wirefree KC-21 transceiver, which is a wire-replacement profile for delivering bytes. In 'command mode', the KC-21 can be configured with AT commands to set up the serial link with the smartphone with settings including baud rate and parity. In 'bypass mode', any data received by the transceiver is sent over the SPP acting as a virtual cable to the smartphone. The user controls the telemetry link using the smartphone application.

IV. USER SMARTPHONE INTERACTION

The smartphone application was written in C# for the Windows Mobile .net platform to allow the user to acquire, store, upload, download and display medical readings from the master node, medical spreadsheets, and the system server. It was also a requirement to enable as many users as possible to participate in the system without having to install any additional software applications. To this end, the system requires only an HTML5 web browser to be able to enter and upload the medical spreadsheet data, as well as to download and display medical readings from the server. Since JavaScript running within a web browser is restricted in its access to the user's machine, an application written for the patient smartphone is always required to interact with the node network over Bluetooth and to store the telemetry locally. But, with respect to entering other patient data and accessing the data already residing on the server, a web browser is designed to present to the user the same features as the smartphone application.

A. Wireless node configuration

For the smartphone to configure and receive telemetry from the master node over the Bluetooth link, they have to be paired and connected. The pairing is explicitly made with the hard-coded PIN code of the master node and with the smartphone as master. The smartphone initiates the Bluetooth connection, allowing the node network to be configured and telemetry to be started and stopped. The BAN network is configured by selecting from which slave nodes to receive data and their respective sampling rates. Separate protocols are used for receiving telemetry and to configure the slave nodes.

B. Patient general health spreadsheets

For monitoring specific parameters associated with cardiac and diabetic conditions, spreadsheet forms were devised to allow users to enter either readings from standard instruments or information obtained verbally regarding the patient's general health. These values are entered by user selection of a discrete value option from multiple list boxes. An example of a typical data entry form is shown in Fig. 2. Instead of allowing the user to enter a specific value, such as in [19] which allowed both speech and web form data entry, responses are constrained to certain values or ranges. Discrete selections allow some commonality between patient responses and trends can be monitored more easily between sessions. List boxes also allow the user to point and select, rather than typing explicitly on a small or virtual keypad, and were also found to be a convenient method for a mobile phone in [20]. Our colour-coding on general health responses also give a visual indication of the general condition of the patient.

C. Database interaction

Multiple measurement files from different sessions and patients are stored on the smartphone using Microsoft SQL Server Compact 3.5 [21], which is a database for desktop and mobile devices similar to the MySQL database at the server. To locate a particular file to transmit, either database can be searched using the patient identification number, timestamp (date and time) and signal type (such as ECG or cardiac spreadsheet) as the search criteria for the file required.

D. Web browser participation

The available controls on the system's web pages are designed to give the user a consistent interface to that of the smartphone application, so the interfaces to the spreadsheet data entry, database search, and display of downloaded spreadsheet, image and waveform files are very similar.

Since the web pages can be viewed both on PCs and the small screens of mobile devices, collapsible regions of the web page allow the user to show or hide relevant sections to reduce the need to perform scrolling. For a downloaded image or waveform file, zoom or pan operations can be performed independently of the server using features of HTML5.

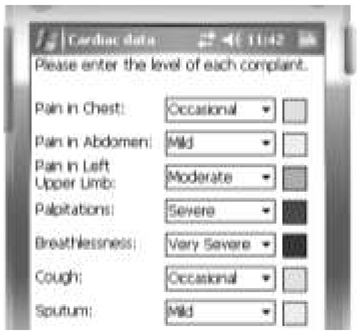

Fig. 2. An example of cardiac patient general health spreadsheet data entry on the smartphone application. The user selects from multiple responses for cardiac condition monitoring. Colour coding gives a visual indication of the patient responses.

V. CONCLUSION

In this paper, the implementation of a system to monitor cardiac and diabetic conditions has been described and a number of areas identified for improvement in previous systems have been addressed through the use of alternative components or techniques. We have used a low power ISM transceiver as an alternative node protocol to Bluetooth and Zigbee and also widened the scope of patient monitoring. By the inclusion of wireless, standard instruments and general health readings an increased diversity of measured parameters is accessible by a web browser.

With the initial system now working, our continuing work includes improving the nodes and communication protocols based on field trials. The recent availability of low power Bluetooth devices, such as [22], has also increased the opportunities for further research into other alternative options. Our ongoing research into new fields, such as wrist pulse telemetry, will also be used to generate possible new insights into the monitoring of these conditions.

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