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Mobile Health Monitoring Systems

William Walker, *student Member, IEEE*, A. L. Praveen Aroul, *student Member, IEEE*, and Dinesh Bhatia, *Member, IEEE*

***Abstract*— Advancements are being made towards a cheap and effective means for health monitoring. A mobile monitoring system is proposed for monitoring a bicycle rider using light weight, low power wireless sensors. Biometric and environmental information pertaining to the bicycle rider is captured, transmitted to, and stored in a remote database with little user interaction required. Remote users have real time access to the captured information through a web application. Possible applications for this system include the monitoring of a soldier in the battlefield and the monitoring of a patient during an ambulance ride.**

I. Introduction

According to the United States Census Bureau [1], the percentage of the total population of persons over the age of 65 has increased and is expected to increase further. According to the Centers for Medicare and Medicaid Services [2], the cost of health care is expected to rise as well. Advancements in health care technologies and services are at least partially responsible for these increases. A low cost and effective means of monitoring persons is desired to both improve the quality of life and to help alleviate the rising health care costs. Using a wireless sensor network, a remote health monitoring system has been developed called Remote Mobile Monitoring System (RMMS).

In RMMS, a Body Sensor Network (BSN) is deployed around the person being monitored. Possible applications for RMMS include monitoring of a soldier in the field, monitoring of a patient riding in an ambulance, and monitoring of police officers deployed on bicycles. Data is viewed in both historical and real time context.

A remote monitoring system is designed to allow remote users to monitor multiple persons in varying locations simultaneously. RMMS uses ZigBee®[3] enabled wireless devices to extract and communicate biometric data. This paper gives a brief description of the implementation of a bicycle based RMMS. This bicycle based RMMS allows the remote monitoring of persons while riding a bicycle. The remainder of this paper is organized as follows. The next section gives a description of the hardware used in the RMMS, including the sensors used and the ZigBee® enabled devices. The following section gives a description of the bicycle based RMMS.

Manuscript received April 7, 2009. The authors are with the Embedded and Adaptive Computing Group in the Department of Electrical Engineering, University of Texas at Dallas, Richardson, TX 75080 USA email: {wpw021000, alp05200, dinesh}@utdallas.edu

II. System Hardware and Network Topology

A. Hardware

The system hardware consists of a wireless sensor node called BioTE which the authors have built in-house using off the shelf components and various sensors interfaced with the BioTE nodes. The BioTE is a two chip wireless solution, containing a MSP430 microcontroller [4] and a CC2420 RF transceiver [5] from Texas Instruments. The BioTE architecture is shown in the Fig. 1.

MSP430 is a 16-bit microcontroller running at 8 MHz with UART and serial peripheral interface (SPI) ports for serial communication. The serial communication peripherals are used to interface with various digital sensors such as the finger based pulse oximeter, skin temperature sensor, ambient temperature sensor, wheel RPM sensor and also to the base station which is currently implemented on a laptop. The low power modes offered by the microcontroller enables us to achieve an extended battery life which is required by the sensor nodes in our system.

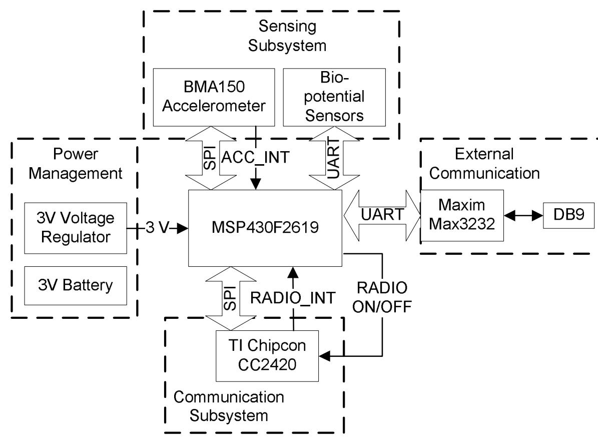

Fig. 1. BioTE Architecture.

CC2420 is an IEEE 802.15.4 compliant transceiver operating in the unlicensed Industrial, Scientific and Medical (ISM) band at 2.4 GHz. It provides IEEE 802.15.4 MAC and PHY layer functionalities providing support for packet handling, automatic acknowledgement, data buffering, data encryption and authentication, clear channel assessment (CCA), and Link Quality Indication (LQI) thereby off-loading the work load from the microcontroller. CC2420 is interfaced to MSP430 using the SPI port.

In RMMS, BioTE can perform two different functionalities of coordinator and sensor nodes. The BioTE node programmed as the coordinator node is responsible for starting the Zigbee® network and allowing the sensor nodes to join the network. It also performs binding with the sensor nodes. It also performs routing the sensor information from the sensor nodes to the base station through the UART interface.

The BioTE node performing the functionality of the sensor node has one or more sensors interfaced to the node through the serial communication interface. The sensors can be active or passive. The active sensors require the user's interaction to take a reading. The passive sensors do not require any user intervention and continuously transmits the reading to the coordinator. As soon as the sensor node joins the network and binds with the coordinator, it begins to take readings from the sensor and transmits the information received from the sensors periodically depending on a pre-set time interval.

The network topology for the Bicycle RMMS is shown in the Fig. 2. The biker's bio-vitals viz., SpO_2, pulse and the skin temperature are transmitted from the biker sensor node to the coordinator node. The bicycle's wheel RPM is transmitted to the coordinator node from the bike sensor node. The coordinator node reads the ambient temperature. The coordinator node collects all the information from the biker sensor node, bike sensor node and transmits them to the data collection server through the cellular network.

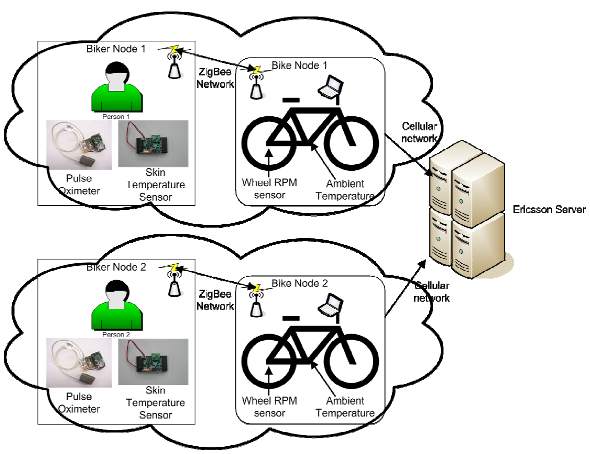

Fig. 2. Bicycle RMMS Network Topology. Sensors attached to the riders connect through the ZigBee® network to a coordinator on the bicycle. Sensor data is uploaded to a remote server.

ZigBee® was used as the communication protocol since only a short transmit distance of less than 3 meters and a very low data rate was required to form these networks of biker and the bicycle along with the various sensors.

B. RMMS Sensors

1) Pulse Oximeter

There were several products for determining the heart rate and the oxygen saturation of the blood available in the medical market but the one that suited our needs in terms of low power consumption was from the Smiths Medical PM Inc. This BCI Medical pulse oximeter board [6] is the smallest and lowest power OEM module. It has a compact size of 39 mm wide and 20 mm deep and consumes only 6.6 mA of current from a single 3.3 V power supply measuring 22 mW typical power. The board provides the $\%SpO_2$ (averaged over 8 pulse beats) in the range of 0 to 99% as well as the pulse rate in the range of 30 -254 bpm in a digital output through asynchronous serial channel. The BCI board also produces flags for conditions like no finger in sensor, sensor unplugged, searching for pulse, searching too long, lost pulse and pulse beep. These conditions are incorporated into the system for triggering alarms.

The oximeter takes continuous $\%SpO_2$ and pulse rate measurements. The BioTE communicates with the pulse oximeter on the serial link and receives the bicycle rider's $\%SpO_2$ and heart rate readings. Once the readings are received, the BioTE transmits them periodically to the base station through the coordinator. The pulse oximeter sends the readings through the serial link at a rate of 60 packets every second. However transmitting the pulse oximeter information every 5 seconds is sufficient to create a valid graph of the biker's oxygen concentration and pulse. Fig. 3 displays the graph for a bicycle rider's pulse and SpO_2.

Fig. 3. Bicycle Rider Heart Rate and SpO_2. The reason for the zero values for heart rate and SpO_2 is where the sensor does not detect a finger in the device, caused by either too much outside light interfering with the sensor LED or sweat on the finger is interfering with the sensor LED.

2) Temperature Sensor

For sensing the skin temperature of the bicycle rider and the ambient temperature in RMMS, we have used the BMA150 accelerometer which has an integrated temperature sensor. The accelerometer was primarily utilized for the activity monitoring framework explained in [7] [8]. For this system, we have only used the integrated temperature sensor of the accelerometer.

In RMMS, separate BioTE nodes are used to collect the ambient temperature and the rider's skin temperature. The BioTE communicates with the temperature sensor using the SPI port. The BioTE node on the bicycle rider queries the skin temperature sensor once every 5 seconds to collect the rider's skin temperature information and then transmits this information along with the pulse, %SpO_2, and battery voltage level information to the coordinator node. The coordinator node on the bicycle queries the ambient temperature sensor once every 5 seconds to collect the temperature information and forwards this information along with other sensor information to the base station.

3) Speed RPM

In RMMS, US4881 from Melexis Inc. [9] is used to gather the speed of the bicycle. US7881 works on the principle of hall-effect sensor [10]. The sensor is placed on the rear wheel and a magnet is placed on the spokes of the rear wheel so that when the sensor passes through the south pole of the magnet, a pulse is generated which is fed to the MSP430 microcontroller. The number of pulses generated by the sensor directly correlates to the rotations of the wheel measured in rotations per minute (RPM) and when the diameter of the wheel is known, the speed of the bicycle measured in miles per hour (MPH) can be calculated.

There is a separate BioTE node in addition to the coordinator node on the bicycle which communicates with the tachometer to read the RPM of the bike and transmits this information to the coordinator node. The MPH calculation is done at the base station.

III. Remote Mobile Monitoring System (RMMS)

RMMS allows the monitoring of mobile persons. A BSN is created around the person using the wireless devices d. An RMMS has many possible applications. One possible application is a military scenario where a soldier's position and vital signs can be monitored from a remote command center. Another possible application is the scenario of a person riding in an ambulance. All information related to the person inside an ambulance can be relayed to the hospital in real time, which will help in preparations for the person's arrival at the hospital. The authors have developed a bicycle based RMMS. The goal for the bicycle based RMMS is to extract information about a bicycle rider and send the information to a remote server, where the information is then presented to a remote user. The bicycle RMMS is used to demonstrate the steps towards "mobile life" [11]. Fig. 4 shows a rider and the bike mounted with the sensors.

Fig. 4. Bicycle RMMS showing the various sensors connected to the rider.

As described in the previous section, the various sensors in the RMMS send data to the coordinator. The coordinator connects with a very small form factor laptop mounted on the bicycle handle bars through a Bluetooth™ connection. A C# application is installed on the mounted laptop and accepts data messages from the coordinator. Upon receiving data from the coordinator, the laptop application accesses the current GPS location of the bicycle and pushes all received sensor and location information to a remote server. The laptop forms an internet connection through a SIM card.

A Java based application running on the remote server accepts data sent from each bicycle and pushes the data into a MySQL database which also resides on the remote server. The time taken to transmit a message from sensor device to remote server is of the order of tens of milliseconds, thus the information gathered on each bicycle rider can be viewed in near real time. The senor readings along with time taken and GPS location provide the ability to overlay the bicycle rider's path on a map. A web application with access to the server's database can display this information to remote users. Fig. 5 is a diagram of the data flow for this system. Fig. 6 is a snapshot of the GUI visible to the bike rider from the mounted laptop.

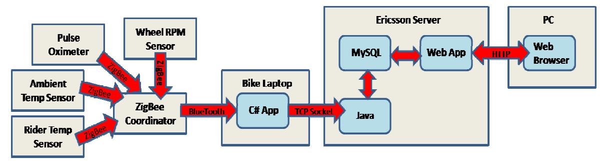

Fig. 5. Bicycle RMMS Data Flow. This is a depiction of how the data travels from sensor to remote server.

Fig. 6. Bicycle RMMS GUI Snapshot.

The authors demonstrated the bicycle RMMS during CTIA Wireless 2009® in Las Vegas on April 1-3, 2009. Two bicycle riders followed a route outside of Las Vegas, where all biometric data (rider's pulse, oxygen saturation, and skin temperature) and bicycle data (ambient temperature, bicycle speed, and bicycle location) was uploaded to a remote database and was immediately viewable through an interface on the show floor.

The RMMS can also be deployed in a stationary environment such as a home or a hospital. In a static environment, a Wireless Sensor Network (WSN) is set up in such a way as to allow continuous coverage in the area being monitored [12]. When activated, sensors send data through the WSN to a gateway device and then to a remote server. An application for this system is the monitoring of elderly population in assisted living communities. Various sensors can be placed in the home of an elderly person, and their activity monitored as they go about their daily routine [7] [8]. If a lack of activity is detected or observed readings are above/below predefined thresholds, a warning signal can be sent to medical personal or family members.

Future work for RMMS includes alternate forms of communication, interface design, and implementation for an ambulance to hospital environment. Currently, the BioTE nodes used for this system communicate using Radio Frequency (RF); however, the human body can create transmission problems. It has been observed that the BioTE nodes have difficulty communicating when a person blocks the line of sight between two nodes. A possible solution is using the body as a communication channel [13]. The next step for RMMS is an implementation in an ambulance to hospital system, as mentioned previously. An interface will be designed for the Emergency Medical Technician (EMT) to easily enter information about the patient. This includes visual parameters like skin color and skin texture. Sensors such as blood pressure, pulse oximeter, respiration, ECG, will send data automatically to the hospital. Vital sign information on a patient and the ambulance's current location will be available to hospital staff to allow them to better prepare for the patient's arrival. As with any system of this nature, security is a big factor, and measures to safe guard the communications from sensor device to data storage are being developed.

IV. Conclusion

Remote monitoring systems allow the monitoring of persons outside of the doctor's office or hospital, thus giving a more accurate history of the person's status. A remote health monitoring system allows medical personnel to service a larger number of persons, reduce hospital visits, enable faster emergency notice, and hopefully reduce health care expenditures. In this paper, a bicycle-based remote mobile monitoring system is described. This system is also intended for mobile persons with a possible application for a soldier in the battlefield or a patient riding in an ambulance. This system employs wireless sensor devices and a description of the hardware was given.

Acknowledgment

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