A MICS Band Wireless Body Sensor Network

Mehmet R. Yuce\(^1\), Steven W. P. Ng\(^1\), Naung L. Myo\(^1\), Chin K. Lee\(^1\), Jamil Y. Khan\(^1\), and Wentai Liu\(^2\)

\(^1\)The School of Electrical Eng. and Computer Sci., The University of Newcastle, Callaghan, NSW 2308, Australia.
\(^2\)Electrical and Computer Eng., University of California, Santa Cruz, CA 95064-1077, USA.

Abstract—This paper presents a MICS (Medical Implant Communication Service) based body sensor network design and implementation for patient physiological data collection for health monitoring purposes. The MICS band offers the advantage of miniaturized electronic devices that can either be used as an implanted node or as an external node. In this work, a prototype sensor network is implemented by incorporating temperature and pulse rate sensors on nodes. Each developed sensor node has the capability of physiological data acquisition and local processing. The sensor node can also transmit data over the air to a remote central control unit (CCU) for further processing and storage. The developed system offers patient mobility as well as medical staff can obtain patient’s physiological data on demand basis via the Internet. The developed system has been optimized for power consumption by using a polling architecture. Some preliminary performance data is presented in the paper.

Index Terms — MICS band, medical network, telemedicine.

I. INTRODUCTION

According to a NEW YORK TIMES report, 5% of people admitted to hospitals, or about 1.8 million people per year, in the United States pick up an infection while staying there. Such infections are called “iatrogenic” induced by physicians, hospitals, drugs, and medical procedures. They are directly responsible for the 20,000 deaths among hospital patients in the U.S. each year, and they contribute to an additional 70,000 deaths, according to the federal Centers for Disease Control (CDC) \(^1\). The dollar cost of iatrogenic infections estimated by the CDC is $4.5 billion. In most hospitals, the number of medical staff is not sufficient. Doctors and nurses often work longer than they are expected and even work double shifts, making them more prone to errors. With increasing number of aging population in most part of the world, healthcare system becomes a global issue.

With the advancement of wireless technologies, high performance and fault tolerant wireless devices can be employed to eliminate medical errors, to reduce workload as well as to improve the efficiency of hospital staff and to improve the comfort of patients. Thus, over the past decade, there has been increased interest among researchers in developing wireless recording and monitoring for real-time physiological parameters (e.g. ECG, EEG, EOG, EMG, Neural, Blood Flow, Blood Pressure etc.) from a patient body in medical environments \(^2\)-\(^7\). With the advanced wireless technology, it is now possible to introduce safe and reliable wireless systems in healthcare area. With successful implementation of such projects, patients in hospital can now sleep in peace without having nurses to wake them up to take samples of their physiological body parameters. Doctors and Nurses will no longer have to go to the ward and do routine checks and yet have the patient’s condition monitored.

Previous wireless data collection systems \(^2\)-\(^7\) used standards such as Zigbee or Bluetooth that do not comply with the medical standard due to their size, power consumption and strong interference from other devices. Considering hundred sensors attached to a patient’s body, such systems become quite bulky to be carried by patients. Therefore, FCC has recently allocated a new band Medical Implant Communication Service band (MICS) at 402-405 MHz with 300 KHz channels to enable the wireless communication of such medical devices to deliver high level of comfort, mobility and better patient care \(^8\)|\(^9\). In addition, the 402-405 MHz frequencies have propagation characteristics conducive to the transmission of radio signals within human body and do not pose as significant risk of interference to other radio operations in that band \(^10\). The MICS is an ultra-low power, unlicensed, mobile radio service for transmitting data to support diagnostic or therapeutic functions associated with implanted medical devices. The MICS band permits individuals and medical practitioners to utilize ultra-low power medical implant devices, such as cardiac pacemakers and defibrillators, without causing interference to other users of the electromagnetic radio spectrum \(^8\)|\(^9\)|\(^13\).

The aim of this project is to build a Wireless Body Sensor Network (WBSN) that is based on the newly available 402-405 MHz MICS band. This band was particularly chosen to provide small size, low-power, faster data transfer and longer communication range. The MICS band is located at an optimum frequency range that promises high-level of integration with the advanced radio frequency IC (RFIC) technology. This results in miniaturization and low-power consumption. While higher frequency causes higher penetration loss, high-level integration becomes difficult at low frequencies. In addition, there exist relatively insignificant penetration loss at these frequencies (10 dB with 10 mm tissue penetration)\(^10\). Moreover, a small antenna design is also difficult at lower frequencies. The antennas for this project are designed as a loop printed around the prototyping boards (See Fig. 6). Combining all these features with the availability of the 402-405 MHZ band internationally offers an attractive frequency choice for the targeted WBSN application.

In the following section, an overview of the Wireless Body Sensor Network is presented; followed by the description of sensor nodes. In Section IV, the CCU is discussed in details. Section VI discusses the firmware and software design and methods for data packing to achieve low power consumption. Conclusions and future work is discussed in Section VI.
II. SYSTEM DESCRIPTION

The wireless Body Sensor Network comprises of sensor nodes, a Central Control Unit (CCU) and a receiver station at a medical center. The WBSN overview is as shown in Fig. 1. Sensor nodes are responsible of obtaining raw data from a human body, processing and transmitting those data via the 1st RF Link using the MICS band to the CCU. The CCU then re-package the data and transmit to the receiver station via the 2nd Link (an ISM band or Internet). The receiver station is capable of displaying all received data on a User Display Graphic (GUI) via the cable RS232 and is also capable of storing all the data in a database of the hospital system. The CCU is targeted to be worn around a patient’s waist to offer mobility to a patient. For the patients with limited mobility, the CCU will be replaced at an accessible location at a distance of up to 10 meter in a house. In the later case, the CCU functions as a storage device for information from sensor nodes. It is connected to a PC, displays real-time information and records the information to the database. The stored information can be sent via e-mails to the database of the hospital on a periodic basis. Pulse rate and temperature are the two vitals signs selected to be monitored in the prototype system. Both Sensor nodes and the CCU are battery operated. Two 3V coin batteries are used to operate the device. Under the Live Monitoring Mode, the worst case scenario can see the battery last for at least 4.4 hours. The sensor nodes and the CCU only weights about 30 grams when fitted with batteries. The collection of data can be done one at a time from these nodes. Thus there is no time restriction and CCU initiated communication (polling) fits best for this application. Every sensor node can sleep most of the time and wake up for a very short time to see whether there is any communication session request from the CCU for that particular node. Only the ASIC processor, which can be designed to operate with a very low clock rate, stays awake. As a result, significant power saving is achieved and battery life is increased, which is very important for medical devices [14].

III. SENSOR NODES DESIGN

Sensor nodes are designed to collect raw signals from a human body. The signal from a human body is usually weak and coupled with noise. First, the signal should go through an amplification process to increase the signal strength. It then passes through a filtering stage to remove unwanted signals and noise. After which, it will go through an Analog to Digital conversion (ADC) stage to be converted into digital for digital processing. The digitized signal is then processed and stored in the microprocessor. The microprocessor will then pack those data and transmit over the air via a transmitter (see Fig. 2).

A. Pulse Rate Sensor Node Design

The overview of the Pulse Rate Sensor Node is shown in Fig. 2. The communication acquires physiological data from sensor interface circuits and transfers this data to a remote system. The communication circuit, sensor interface electronics are attached together with the sensors, as depicted in Fig.2. Microcontroller PIC16F877 and the transceiver AMIS-5210 are selected in the project because of the following reasons: overall cost saving, low-power consumption, size, and the suitability operating at MICS band and for physiological data processing. The PIC controller has 10-bit and 8-bit ADC built in which eliminates the need for an external off-shelf ADC.
As can be seen, the pulse rate sensor node comprises of several blocks including the pulse detector, the low-noise op-amp stage, filtering, ADC, signal processing by the microcontroller and the transmitter. The sensor consists of an infrared emitter (880nm) and a phototransistor. Light is shone through the tissues and variation in blood volume alters the amount of light falling on the detector. Pulse rate varies from person to person, different time of the day, person conducting different activities and different age group.

When the heart beats, a pressure wave moves out along the arteries at a few meters per second. This pressure wave can be felt at the wrist, but it also causes an increase in blood volume in the tissues which can be detected by a plethysmograph. This word comes from the Greek “plethysmos” for increase and is a term for a “fullness” (i.e. change in volume) measuring device [11]. Refer to Fig. 4 for a complete pulse rate pattern. Pulse rate or heart frequency is calculated based on the RR-interval. Calculation of heartbeat per min requires the user to take the period between the 2 consecutive R’s. Let this period be T. Then the beats per minute (bpm) is calculated as 60 / T = bpm. Example if the 1st R is at 200ms and the 2nd R happens at 1000ms. The period is 800ms. Therefore the heartbeat of this person is 60/800ms = 75bpm. Human heartbeat ranges between 50bpm to 200bpm. These figures indicate that the frequency range of human heartbeat is between 0.83Hz to 3.33Hz:

$$50\text{bpm} = \frac{50}{60} = 0.83\text{Hz}$$
$$200\text{bpm} = \frac{200}{60} = 3.33\text{Hz}$$

The filter stage is designed at the lower cutoff frequency of 0.5Hz and an upper cutoff frequency of 3.5Hz. The ADC samples the input to allow calculation of pulse rate by the microcontroller. The transmitter performs data package and transmit the Manchester Coded data over the air to the CCU via the MICS band. Hardware implementation of the Pulse Rate Sensor Node is shown in Fig. 4. Op-amp stage amplifies the input by 10000 to saturate the input signal, thus a square waveform is expected at the output of the op-amp. A sample pulse rate after op-amp is shown in Fig. 5.

B. Temperature Sensor Node Design

The overview of the temperature sensor node is shown in Fig. 5. Temperature sensor produces analog voltage with respect to temperature. The ADC samples the voltage and converts to a digital data for RF transmission. The transmitter adds some overhead and package the data for transmission. See Fig. 6 for the hardware implementation of temperature sensor node.
IV. CCU DESIGN

The proposed block diagram of the CCU is shown in Fig. 6. Incoming data passed through the transceiver and be stored in the microprocessor. The data will then be converted to RS232 level by the level shifter and send to the PC. The PC will have a Graphic User Interface (GUI) to display the data on the screen of the PC and at the same time save the data into a database. The CCU is located at the waist of the patient or located an easily accessible place. The primary function of the CCU is to collect all data from sensor nodes via the wireless MICS link and then transmit to the Data Collection Center via the Internet or an ISM Band. The target distance for 1st RF Link (MICS Band) is 1-10 meters. The target distance for 2nd RF Link (ISM Band or via the internet) is 10km and more. The wireless data transfer part of the Fig. 6 is targeting to use the mobile/cellular network systems as being done by the projects in [4][5]. The CCU differentiates incoming data by its address. This will help to store the correct sensor data to the correct location. The CCU is able to display real time data on a User Graphic Interface (GUI) and at the same time stores data in a text file.

V. SOFTWARE AND FIRMWARE DESIGN

For this body sensor network project, three major components are implemented. One software program for a User Graphic Interface (GUI), one Firmware for the CCU, and another Firmware program at sensor nodes. The GUI software is designed to display the collected data from sensor nodes and to store the collected data as a text file. The software program also accommodates a serial communication to interact with the CCU. The GUI allows the medical personnel to enter the patient’s information, diagnosis, doctor-in-charge and it displays real time graph of patient’s temperature data and pulse rate. The GUI is shown on Fig. 7. It can store the data into a database that can be seen at the medical center for reference for doctors. Refer to Fig. 8 for a sample of data storage file. Firmwares define the communication protocol and are required in all sensor nodes, CCU, and the receiver at the data collection center. They aim to reduce the power consumption of the sensor node and the CCU.

In this prototype system, the temperature sensor is programmed to wake up and collect data every 10 minutes while the pulse rate sensor collects data every 5 minutes. The data will be stored in the EEPROM on the sensor nodes. The sampling of data is through the internal ADC of the microcontroller. For temperature sensor, sampling is performed every 100ms. As for the pulse rate sensor, sampling is performed every 50ms for 10 seconds. The microcontroller computes the pulse rate during these 10 seconds period and multiplies by 6 to obtain the heartbeat per minute.

In order to save power consumption, the data will not be sent every 5 or 10 minutes. Instead it will collect a block of data and send this block of data every hour. Since the transmitter drawing high current, this method will ensure the
The transmitter power with the above setting is 25mA. The CCU uses low power RF Sniff mode. This mode enables the receiver to wake up at times to “sniff” received RF signals and then return to “sleep” if a signal is not detected [12]. Sniff mode current consumption is 75uA while receive current consumption is 7.5mA.

The communication protocol is designed such that the central control unit becomes centralized between sensor nodes and user interface software. It includes one way wireless protocol and two-way RS 232 protocols as shown in Fig 9. The transmitter power for the MICS band is limited by the regulation. It can be chosen maximum is at 25 µW (i.e. EIRP=-16dBm) [8][9]. In the prototype system, transmission range is measured for a range of transmitter power as shown in Fig. 10. The range is basically limited by the receiver sensitivity of the AMIS transceiver [12].

The work in this paper has focused on an external sensor node design for medical monitoring. The goal of future work is to design a miniaturized sensor node that is small enough to make them implantable where the nodes will be controlled by the external central unit. The CCU will trigger the sensor node to perform a measurement only when it is necessary. In this
communication we can keep the power consumption significantly low so that the battery life can last several years [14]. The microprocessor (microcontroller) used here is too powerful, in future a lower range microprocessor will be used for both implanted or external sensor nodes to reduce size as well as power consumption. Currently a custom chip, that will include a low-power transceiver and ASICs as a microcontroller, is being developed [14][15]. This chip is especially targeted for fully implantable sensor nodes. Future work also involves designing more sensors to monitor other vital signs such as blood pressure, oxygen saturation level, ECG, etc.

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