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Full Length Research Paper

Enhancement of real-time multi-patient monitoring system based on wireless sensor networks

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Portable patient monitoring device has become increasingly important in Hospital wards to record real-time data during normal activity for better treatment. However, the current quality and reliability have not been satisfactory due to the size, weight, distance of coverage and also high power consumption. This paper provides several solutions for enhancing the reliability and improving the power management of the real-time multi-patient monitoring system (MPMS). A reliable wireless personal area networks (WPANs) based on digital signal processing (DSP) was introduced and developed, which consists of twenty remote nodes and a central node with pc-based graphic user interface. Sleep strategy and other techniques (dynamic voltage, frequency scaling) have been used to achieve low power management and assisted power control. Results indicate that, multiple WPANs approach out-performed the single one in respect of efficiency and reliability.

Key words: Multi-patient, wireless personal, power consumption.

INTRODUCTION

Diagnosing and continuous record of real-time data by the use of portable patient monitoring system during normal activity would be beneficial for medical practitioners to do proper and better treatment; also it would be useful for health care providers to improve diseases management (Otto, 1999). This challenge attracts many researchers to invent a new design and deploy comprehensive patient monitoring solutions for hospital health care system (Connor et al., 2001). Advances in wireless networking have opened up new opportunities in a variety of applications (Pierce, 2001) including healthcare systems (Lorincz et al., 2004; Lubrin et al., 2005; Dayu,` 2010; Dishman, 2004; Jafari et al., 2005). Although present systems in hospitals allow continuous monitoring of patient vital signs, these systems require the sensors to be hardwired to nearby, bedside monitors or PCs, and essentially confine the patient to his hospital bed. The advents of Wi-Fi and Bluetooth have facilitated breaking the cord between the non-invasive patient sensor and the bedside equipment (Lubrin et al., 2005). These systems do not require the patient to be confined to his bed and allows him to move around freely in his room but requires him to be within a specific distance from the bedside monitor. For example, the range of transmission for typical Bluetooth systems is about ten meters. Beyond this distance, it is not possible to acquire data. Patient mobility beyond his hospital room can be incorporated by using a network of such nodes placed at appropriate distances in order to transfer data to the monitoring station. However, network nodes that use protocols such as Bluetooth require a larger volume and higher power consumption. This indirectly indicates a higher cost per node and a fairly high burden on its power source, further increasing its size and cost. Depending on the size of the hospital, several such nodes might be required resulting in a much higher system infrastructure cost. Moreover, such protocols are meant for moderate to high bandwidth applications where relatively large packets of data need to be transmitted and received. In the case of patient vital sign monitoring, the data packet size is much smaller, which seems to suggest that networks using such protocols might seem impractical.

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Obviously, low power, low cost network nodes are required for such applications.

This paper proposed several solutions for enhancing the reliability and improving the power management of the real-time multi-patient monitoring system (MPMS). The system consists of nodes that consume very low power and are extremely small in size. These slave nodes are specifically designed for low power consumption, with minimal circuit components. They are intended for small packet, long distance range applications and typically consist of a low power processor with minimal resources and interface capabilities. They also have a conservative transceiver that is capable of transmitting 8 bytes of data at a time and has a moderate transmitting range of about 130 m. Therefore, WPANs seem to be a perfect fit for remote patient monitoring.

RELATED WORKS

Recent development in the fields of microelectronics, communication/networks, integrated optics, and other related technologies enables wireless patient monitoring sensors to sense and measure the data more efficiently, accurately, low in cost, small in size, and body-wearable. As the name suggests, this kind of devices or systems are developed to monitoring a health care environment, for prevention, diagnosis, monitoring and treatment. Design configurations of the wireless health monitoring systems for infrastructures were developed by Wag and Liao (2001). Special attention is paid to the low frequency response characteristics of the wireless transmission system. Zimu (2010) focuses on design and develops a wireless health monitoring prototype system with the initial emphasis on measuring the electrical activity of the heart. He considered two types of wireless heart monitors for indoor/outdoor use and tradeoffs between power and communication range. Hui (2007) presents integrated circuits and system design for sensor node, including analog and digital blocks in creating a RF data link. To minimize the power consumption of the sensor node, it suggested that some of the computations are performed digitally in the sensor node before the results are transmitted to the rest of the system. Priya (2009) presents a prototype of a wireless health monitoring system capable of sending SMS related to the health status of the patient. The project is divided in to three stages; data acquisition, data processing and communication.

The monitoring system automatically transmits the information to the doctor's hand phone on the mobilenetwork as a SMS message via a GSM device / SMS gateway, and at the same time, the system will update the hospital database periodically. Figueiredo (2010) presents a low power wireless acquisition module for use within wearable health monitoring systems and ambient assisted living applications. The acquisition module provides continuous monitoring of the user's electrocardiogram (ECG) and activity, as well as the local temperature at the module. The module is placed on the chest of the user, and its wearability is achieved due to its fabrication based on a flexible PCB, by the complete absence of connecting wires, and also, as a result of the integration of flexible and dry ECG monitoring electrodes on the acquisition module, which do not require preparation with electrolyte gel.

THEORETICAL BACKGROUND

The communication link

For setting up the communication link, WPANs was introduced, where data is required to be periodically sent to the central node using time division duplex (TDD) scheme. The WPANs operates with a small network stack of three layers as illustrated in Figure 2. The Application layer (APP) is concerned with acquiring the preprocessing of the pulse rate data through the analog circuitry and the DSP processor, and it is also concerned with the development of user application program, to sample, compress, decompress, construct, display and analyze the pulse rate signal on PC. The medium access control layer (MAC) through the PIC 18F2550 microcontroller are responsible for maintaining the Network including the link establishment, changing the modes data transmission, holding the all network packet types and nodes' addresses, network management and transfer of acquired data. This involves interfacing to the application layer where the sampled data is required to be synchronized when sent, and also requires interfacing to the physical layer (PHY), which is required to interface to the XBEE module and the MAC layer. The physical layer is also responsible for obtaining 'reliable' communication between nodes. That is, the data received at each node is passed to the MAC Layer to be error-free and to be performed. The physical layer will be implemented with data whitening (DW) and CRC to minimize DC bias of the packet and to provide error detection. The WPANs specifies different packet types including connect request, disconnect request, acknowledge/poll, request settings and data transfer.

The WPANs mechanism

The initial start-up of the system is performed in the APP

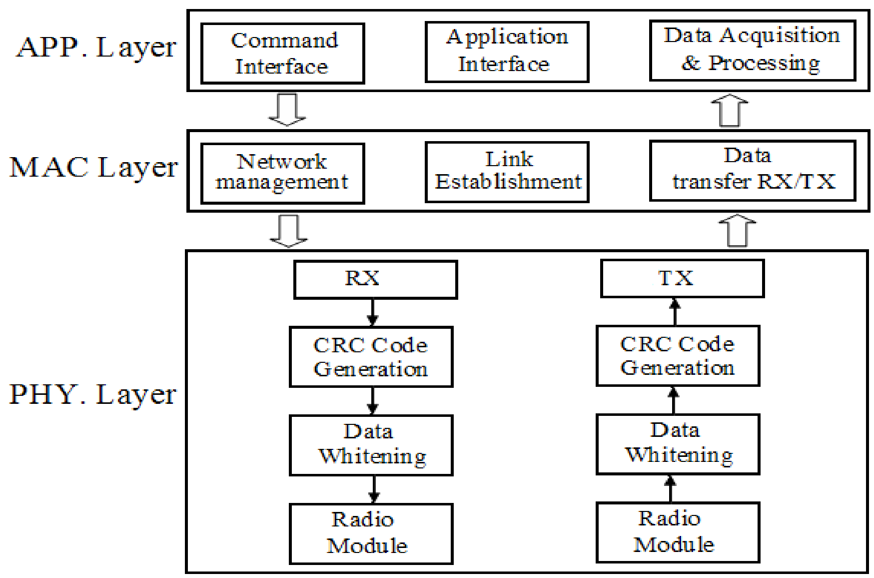

Figure 1. WSP architecture.

layer of the master node. The GUI, created in visual basic 6.0, will prompt the user on initializing the wireless connection. This will in turn pass information via a USB port to the PIC 18F2550 microcontroller communication processor which contains both the MAC layer and the PHY layer. A packet containing information on the network management is passed onto PHY layer. Here the decoding of the message and the creating of the transmission packets are executed, before the data is finally sent through the transceiver. The remote node's transceiver receives the packet and passes it onto the PIC 18F2550 microcontroller. The decoding of the message is done in the PHY layer and then the information is passed onto the MAC layer. The MAC layer first checks if it is a valid packet from the central node. If so, it will reset the clock and realize the transmission slot time. A query is then passed onto the APP layer, which begins sampling pulse rate data and storing it into PIC 18F2550 microcontroller's flash memory as shown in Figure 1.

The MAC layer, just prior to transmission time, changes the mode of the transceiver to transmit mode, and then extracts a sample of pulse rate data and passes it onto the PHY layer. This information is once again formatted and created into a packet to be sent back across to the central node. Finally, the information is received and yet again passed through the particular layers until it reaches the PHY layer. Once the PHY layer has received substantial information from the remote nodes in the network, it is then able to create the pulse rate signal on the PC. The size of time slots depends on the symbol rate of the XBEE module as well as the time required for the XBEE to switch between receiving and transmitting modes.

Power consumption

DSP systems incorporate a number of hardware or software features designed to give greater control over the system power consumption. Therefore, a number of programming techniques can be used to reduce power consumption (Verbauwhede et al., 2000).

SYSTEM DESIGN AND IMPLEMENTATION

Hardware implementation

Central node

The right side of Figure 2 shows the functional diagram of the central node, how the XBEE-PRO module transmits the management and control packets and receives the transmitted data. The PIC 18F2550 microcontroller manages the data transfer and controls the transmission link as well as PC interfacing.

Remote slave node

The remote node can be selectively configured to provide master-slave topology, or to form Stand-Alone, that is, portable DSP-based arrhythmias monitoring system. In the left side of Figure 2, the INA326 instrumentation amplifier acts as a front-end signal acquisition system, as the OPA2335 provides the amplification. Anti alias, filters and feeds the TMS320VC5509A, which is an ever most power-efficient DSPs generation, with a roadmap as low as 0.05 mW/MIPS and speeds up to 200 MHz. Then, the PIC digitizes the signal, applies the desired preprocessing algorithms, and controls and manages the data transfer from/ to the peripherals like JTAG header, USB header, flash memory and the XBEE modem.

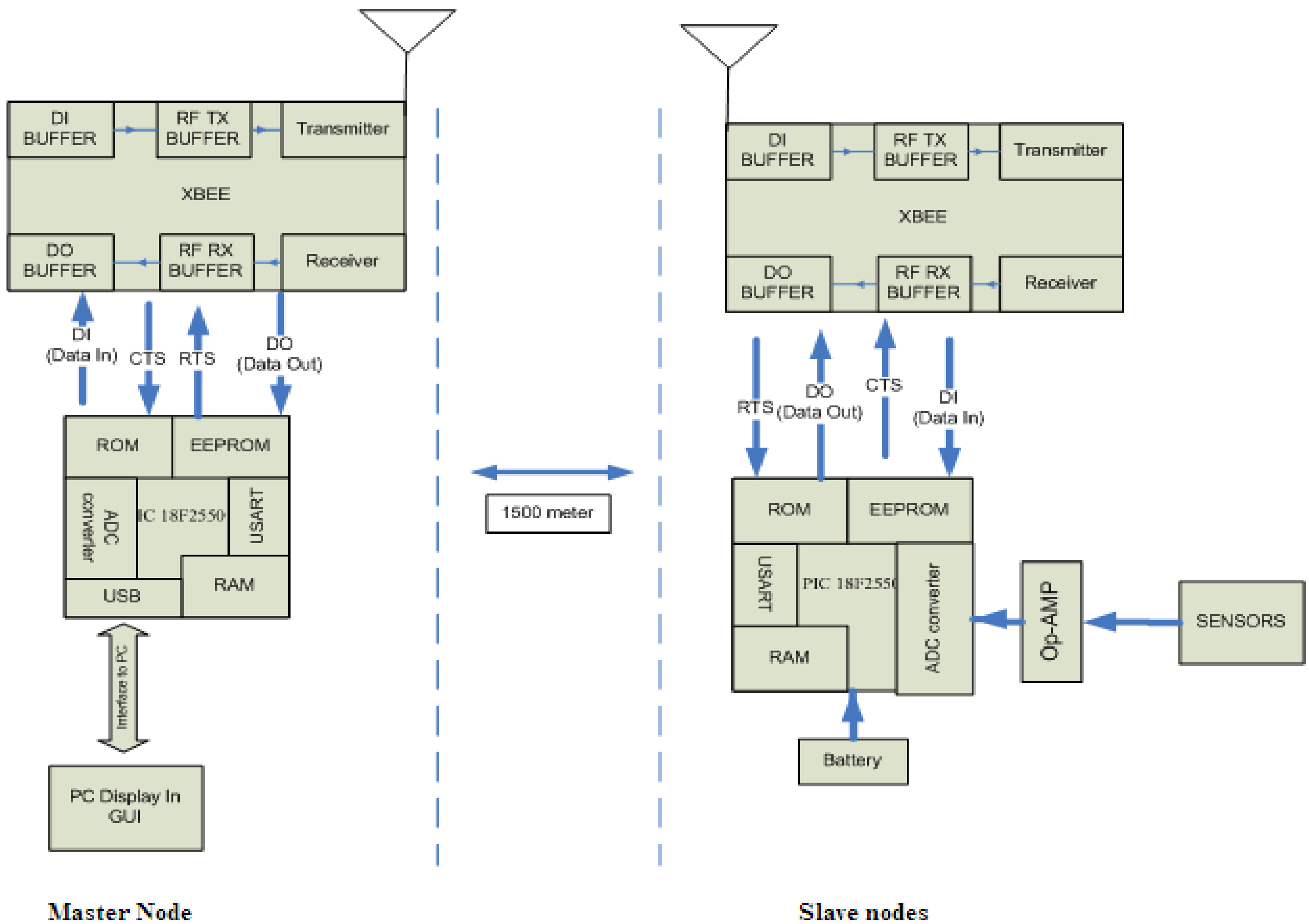

Figure 2. System block diagram.

Software design

Remote node algorithms

As introduced above, the prototyped remote node has two types of operating modes, stand-alone and slave-master. Thus, it has separate program for each mode of operation. It is apparent that both modes require certain common basic support functions, and accordingly, the software should be structured modularly. So these supporting routines can be incorporated into any of the programs as a common operational approach to allow minimal power consumption. All These algorithms are TI-DSP on-chip algorithms.

Figure 3 illustrates the remote node algorithm's flowchart. The code is written in code composer studio v. 3.1. Once power-on, the PIC chip boots up from the internal flash memory. Then the program initializes and waits user to input the mode type (if stand-alone); meanwhile a GUI window will open, which allows the user to choose the desired function. Accordingly the PIC chip starts the needed support functions like acquiring ECG signal, ADC conversion, filtering, detecting arrhythmias, displaying real ECG signal, displaying detection report, printing, sending advising /warning messages or storing data. At the same time, the PIC controls the peripherals to perform the suitable operation. But if it is a master-slave mode, the PIC, after acquiring the signal, will convert it into ADC, filter, compress and store data until the central note establishes a new transmission link in its specific time slot. If so, the PIC will decompress and pass the data to the XBEE modem for transmitting.

Central node algorithms

These algorithms is divided into two parts, the PIC algorithms and the PC-based application algorithms. Figure 4 illustrates the PIC Program. Upon power-on, the algorithm loads and initiates the processor I/O and TDM ports, sets the modem to the active mode, configures the time slots register, initializes the connection and synchronization period assigning each (online) remote node with a particular time slot and changes into receiving mode once the entire packet is sent. Once the synchronization is accomplished, it receives data from the particular remote node at its given time slot, and sends the data to the PC. This cycle will be repeated for certain numbers of times before central either resynchronizes or disconnects. In the PC-based application program, state-of-the-art tools have been used in creation of the computer system using visual basic 6.0 to acquire, analyze, construct and display the patients ECGs periodically.

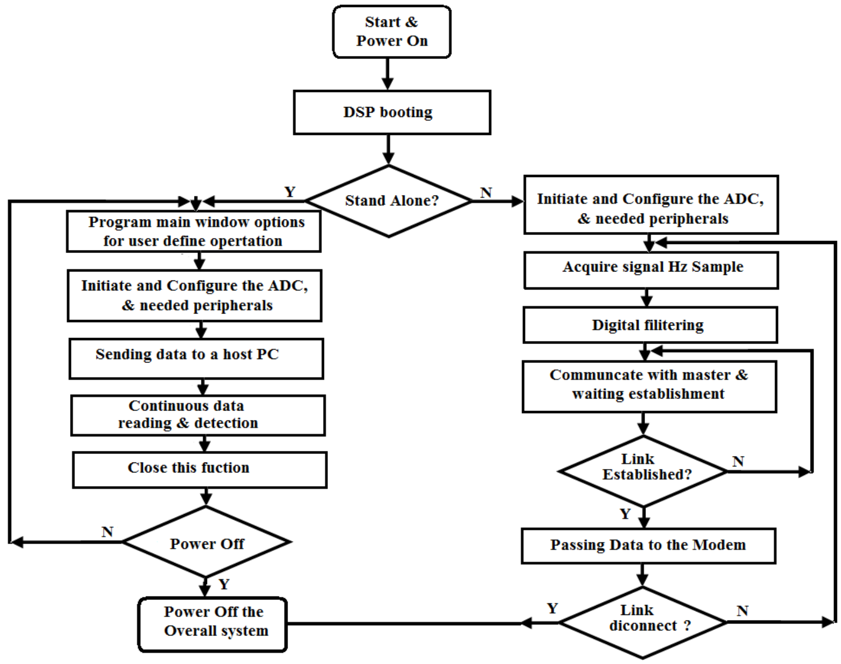

Figure 3. Remote node algorithm.

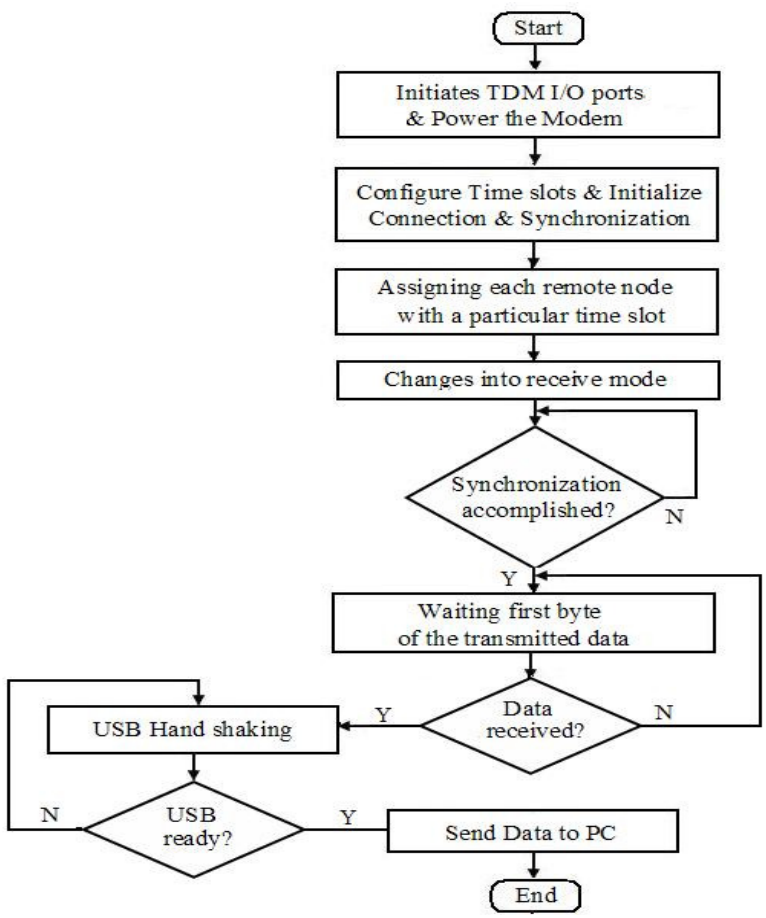

Figure 4. PIC 18F2550 microcontroller -based.

Table 1. System-based versus manual, arrhythmias detection parameters result.

Patient no.	Results method	HBR	R-R(ms)	QRS(ms)	QT/QTc (ms)	ST(mv)
1	System-based	64	165	85	393/392	0.034
	Manual	62	161	83	394/393	0.042
2	System-based	75	140	78	368/374	0.025
	Manual	72	146	76	370/372	0.031
3	System-based	82	168	83	351/369	0.017
	Manual	81	164	79	359/368	0.022
4	System-based	61	128	73	374/381	0.062
	Manual	62	130	72	375/384	0.079

Table 2. Remote node power dissipation (operating).

No	Part	Power before (mA)	Power after (mA)
1	XBee	40.00	20.00
2	ISD4004 voice	15.00	15.00
3	ECG front-end analog circuitry	03.10	0.00
4	Keypad +LCD	00.06	00.06
5	TMS320VC5509A DSP and its peripherals	46.00	36.60
	Total	104.16	71.66

RESULTS AND DISCUSSION

Through the experimentation of this implemented WPANs architecture, it was realized that relatively precise results were achieved if the network was resynchronized once every six cycles. However, with the inclusion of more nodes, this will almost certainly result in requiring more resynchronization as regular intervals. System-based results versus manual results of arrhythmia detection and ECG wave parameters values for four patients have been presented in Table 1. Power consumption forms an important characteristic of our design; so three techniques has been followed and considered to achieve low power consumption, first, because power consumption is proportional to the square of supply voltage, scaling power supply voltage, reducing the switching frequency (Jafari et al., 2005), and Data-Block processing algorithms was applied to the implementation of an Integer Filters. The total power consumption is measured using TI-VC5509A power estimation spreadsheet (Sunwoo et al., 2007). The implemented techniques achieve a reduction in energy consumption of 30.2%. Table 2 shows remote-node power dissipation before and after applying these techniques.

Conclusion

The present system provides twenty patients with real-time, low-power, low-cost, long-distance, and dual-mode monitoring, which is suitable for poor people in the Third-World countries, where there are no telephone lines, web-based systems, and GPS. The use of the PIC18F2550 and the XBEE communications processor for building blocks of the monitoring system has the benefits of intelligence, compact size and reliability. By the aid of this highly-integrated chips, external components and hence wirings are kept to a minimum. A reliable wireless personal area networks (WPANs) has been introduced and described, and also a powerful digital signal processing techniques was used to develop this DSP-based system. Further advantage of this system is its low-power consumption, which is attractive for portable applications.

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