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Design and Development of Low Power Wireless Sensor System for Measurement and Monitoring of Bio-Medical Parameters

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ABSTRACT

This paper presents the design and development of a low power embedded system for the measurement and monitoring of physiological parameters like body temperature, respiration, blood pressure and ECG. The design is developed around a low power microcontroller MSP430 from Texas Instruments. A wireless sensor module is used to transfer the data from microcontroller to the PC and a graphical user interface (GUI) is developed to display the measured data in the graphical form.

KEYWORDS: Embedded system, Wireless sensor network, Zigbee , MSP 430 Microcontroller, ECG , Pulse rate

I. Introduction

Current health care systems which are aimed and optimized for reacting to crisis and managing illness are facing new challenges, due to rapidly growing population and unfavorable climatic conditions. According to a survey of the Census, the number of adults age 65 to 84 is expected to double from 35 million to nearly 70 million by 2025 . This trend is global, so the worldwide population over age 65 is expected to more than double from 357 million in 1990 to 761 million in 2025. Also, the average health care expenditures has doubled during this decade when compared to earlier years. It is expected that health care expenditures will reach almost 20% of the Gross Domestic Product (GDP) in less than 10 years, threatening the wellbeing of the entire economy [i]. All these statistics suggest that health care needs a major shift toward more scalable and more affordable solutions. Restructuring the health care systems toward proactive managing of wellness rather than illness, and focusing on prevention and early detection of disease emerge as the answers to these problems. Wearable systems for continuous health monitoring are a key technology in helping the transition to more proactive and affordable healthcare .Wearable health monitoring systems allow an individual to closely monitor changes in her or his vital signs and provide feedback to help maintain an optimal health status. If integrated into a tele-medical system, these systems can even alert medical personnel when life-threatening changes occur. In addition, patients can benefit from continuous long-term monitoring as a part of a diagnostic procedure, can achieve optimal maintenance of a chronic condition, or can be supervised during recovery from an acute event or surgical procedure. Long-term health monitoring can capture the diurnal and circadian variations in physiological signals. Keeping in view these factors the authors tried to develop a low power embedded system to measure and monitor the various physiological parameters [ii]. The recent progress in several areas of technologies, such as microelectronic, information technology (IT) and medicine, has enable healthcare professionals to provide their services to patient remotely, without much interfere to their daily life. Researchers and scientists worldwide are therefore gaining momentum to develop a low-power, small size, wireless, wearable medicine device, or commonly referred to the body sensor. Patient is equipped with the body sensor in order to allow temporal physiological data, such as electrocardiogram (ECG or EKG), heart rate and blood pressure, to be collected. The existing telecommunication system is used to connect the patients and service providers for healthcare management and disease diagnostics purposes [iii].So the microcontroller based systems are becoming more and more popular, due to their low cost, compactness and low power features. These devices are simple to use and are highly portable. As the prime objective in the design of such embedded systems is the low power dissipation, naturally the selection of the processor and the wires module play an important role . The MSP430F1611 is a 16-bit processor based on Von Neuman architecture designed for low power applications from Texas Instruments [iv]. The registers in the CPU are all 16-bit wide and can be used interchangeably for either data or address. The important advantage of this processor is, it is extremely easy to put the device into low power mode. There are five low power modes and there are two successive approximation ADCs, ADC 10 and ADC 12. In the present work ADC 10 is used.

Currently three main wireless standards are used namely WiFi, Bluetooth and ZigBee respectively. Wi-Fi networks, a standard named IEEE 802.11, is a radio technology to provide reliable, secure, fast wireless connectivity. A Wi-Fi network can be used to connect computers to each other, to the Internet, and to wired networks. Wi-Fi networks work in the unlicensed 2.4 GHz and 5 GHz radio bands, with a data rate of 11 M bit/s or 54 M bit/s. They can provide real-world performance similar to that of the basic 10 BASE-T wired Ethernet networks. Unlike a wired Ethernet, Wi-Fi cannot detect collisions, and instead uses an acknowledgment packet for every data packet sent.

Bluetooth is a protocol for the use of low-power radio communications over short distance to wirelessly linked phones, computers and other network devices. Bluetooth technology was designed to support simple wireless networking of personal consumer devices and peripherals, including PDAs, cell phones, and wireless headsets. Wireless signals transmitted with Bluetooth cover short distances, typically up to 10 meters. Bluetooth devices generally communicate at less than 1 M bps in data transmission. The wireless Bluetooth technology is popularly used in several fields. Many researchers have used Bluetooth technology to their monitoring systems. Wireless mobile monitoring systems for physiological signals not only increase the mobility of uses but also improve the quality of health care .

ZigBee is a low-power, low-cost, wireless mesh networking standard. The low power allows longer life with smaller batteries, the low cost allows the technology to be widely developed in wireless control and monitoring applications and the mesh networking provides high dependability and larger range.ZigBee operates in the industrial ,scientific and medical radio bands with 868M.Hz,915M.Hz,and 2.4G.Hz range. ZigBee operates in the industrial, scientific and medical radio bands with 868 MHz, 915 MHz, and 2.4 GHz in different countries. The technology is intended to be simpler and less expensive than other WPANs such as Bluetooth .Of those, ZigBee is the most promising standard owing to its low power consumption and simple networking configuration.[v].

Network devices, whether wired or wireless, are commonly described by the Open Systems Interconnection (OSI) reference model. This abstraction model was developed by the International Standards Organization (ISO), starting in the 1980 description of communication-related protocols and services. The generic seven-layer model is applied to all network and media types.[vi].The adaptation ISO-OSI network reference model for ZigBee purposes is shown in the Figure 1. ZigBee network model does not use presentation, session or transport layer and user application is directly tied into Application layer (APL). The ZigBee Alliance selected the IEEE 802.15.4 standard, released in May 2003, as the wheels and chassis upon which ZigBee networking and applications have to be constructed. IEEE802.15.4 defines three frequency bands to employ a standard over the world. The various frequency bands available within the IEEE 802.15.4 and with the available bit rate and modulation method are shown in Table 1. The ZigBee specification identifies three kinds of devices that incorporate ZigBee radios, as shown in Figure 2. with all three found in a typical ZigBee network [vii].

- **Coordinator (ZC):** organizes the network and maintains routing tables,
- **Routers (ZR):** can talk to the coordinator, to other routers and to reduced-function end devices,
- **End devices (ZED)**: can talk to routers and the coordinator, but not to each other

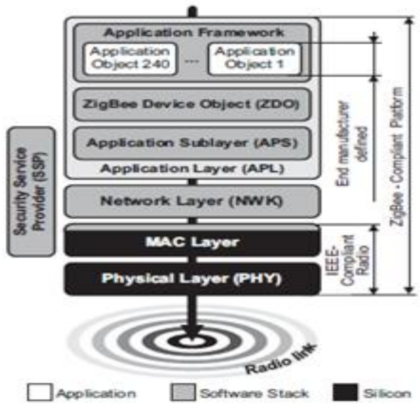

Figure 1. Adaptation ISO/OSI to ZigBee standard

In the present work , a low-Power 2.4 GHz RF Transceiver, The CC2500 Zigbee module from TI that provides additional low power dissipation features ,which is the most sought after solution in biomedical applications is used. The CC2500 is a 2.4 GHz transceiver designed for very low-power wireless applications .

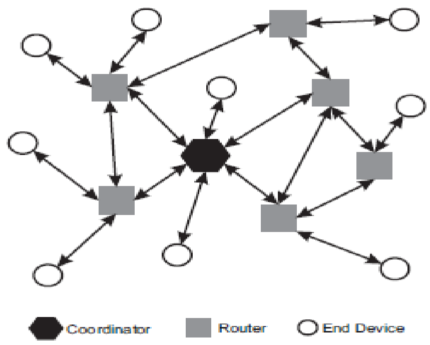

Figure 2. ZigBee network incorporating

The circuit is intended for the 2400-2483.5 MHz ISM (Industrial, Scientific and Medical) and SRD (Short Range Device) frequency band. The RF transceiver is integrated with a highly configurable baseband modem. The modem supports various modulation formats and has a configurable data rate up to 500 k. Baud. CC2500 provides extensive hardware support for packet handling, data buffering, burst transmissions, clear channel assessment, link quality indication, and wake-on-radio[viii].

Table 1. Different parameters of IEEE 802.15.4

Parameter	868 M.Hz	915 M.Hz	2.45 G.Hz
Frequency Band	ISM	ISM	ISM
Area	Europe	USA / Australia	World wide
Bit-rate	20 kbps	40 kbps	250 kbps
Number of channels	1	10	16
Modulation	BPSK	BPSK	O-QPSK

II. Material and Methodology

The present design consists of a three electrode ECG sensor,a digital temperature sensor,, pulse rate sensor (Heart beat sensor) which are suitably interfaced to the MSP430 microcontroller. The photograph in the Figure 3 shows the details of the design ..

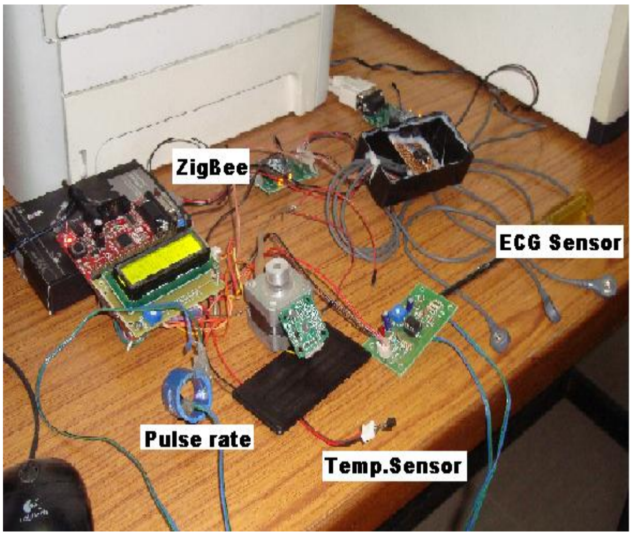

Figure 3. Photograph showing the experimental details.

2.1 Three electrode ECG sensor : Three electrode system is a simple method of electro cardiograph . This method is used in emergency departments, telemetry monitoring and during medical procedures. The Three electrodes are placed on right arm (RA), left arm (LA) and right leg (RL). For bipolar leads (I, II& III), one pair is selected for monitoring and the other one is used as a ground. For augmented leads (avR, avL & avF), one is exploring lead and the other two are connected to zero potential. Anterior wall myocardial ischemia is not suitably monitored by this system. The electrodes detect the small voltages of the order of hundreds of micro volts generated by heart activity. But the signal is too small and contains a lot of added noise. It is very important that, the ECG signals are differential signals while the power line voltages are common mode, so the noise can be reduced by using differential amplifiers (Instrumentation amplifiers). In the present work, the electrodes measure the bio potentials on the surface of the skin. But these bio potentials are very weak and they are easily contaminated by noise. So, to remove the noise, a suitable signal conditioning circuit is designed using a high CMRR instrumentation amplifier and four operational amplifiers which provide suitable filter operation, as shown in Figure 4.

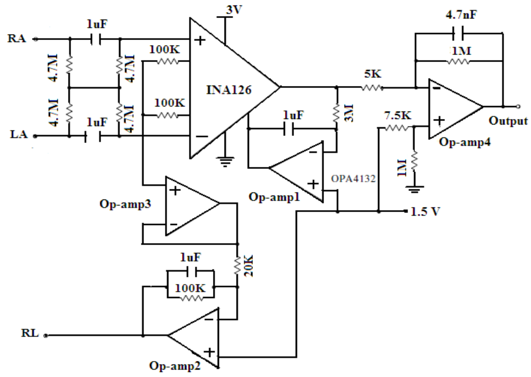

Figure 4. Signal conditioning circuit for ECG sensor

2.2 Pulse rate measurement sensor : Pulse rate denotes the number of heartbeats per second and is usually expressed in beats per minute (bpm). In adults, a normal pulse rate is around 60 to 100 times a minute during resting condition. The resting pulse rate is directly related to the health and fitness of a person and hence is a very crucial physiological parameter. It can be measured at any spot on the body where the pulse is felt with fingers. The most common places are wrist and neck. From this heart rate in bpm is evaluated easily. To measure the pulse rate a simple pulse-oxymeter is constructed using a simple arrangement. In this method the change in blood volume in a finger artery while the heart is pumping the blood is found . The arrangement consists of an infrared LED that transmits an IR signal through the fingertip of the subject, a part of which is reflected by the blood cells. The reflected signal is detected by a photo diode sensor. The changing blood volume with heartbeat results in a train of pulses at the output of the photo diode, the magnitude of which is too small to be detected directly by a microcontroller. So, a two-stage high gain, active low pass filter is designed using two operational amplifiers (Op-Amps) to filter and amplify the signal to appropriate voltage level so that the pulses can be counted by a microcontroller [ix]. In the present work the MSP230F1611 Microcontroller is used to count the pulses .This pulse rate is displayed on a 2x16 LCD module. The signal conditioning circuit is shown in Figure 5.

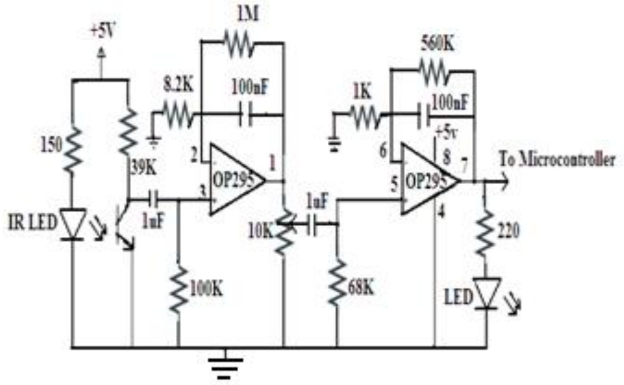

Figure 5. Signal conditioning circuit for pulse rate measurement

2.3 Temperature Sensor : The temperature of the body is measured by using a simple digital temperature sensor which supports I^2C standard. The TMP100 is a digital temperature sensor which can be operated over a temperature range of -55^0 C to $+125^0$C . This temperature sensor does not require complicated signal conditioning circuitry. This sensor is interfaced to MSP 430 microcontroller by using the port pins $P_{2.0}$ and $P_{2.1}$.The simple interfacing model is shown in Figure6.

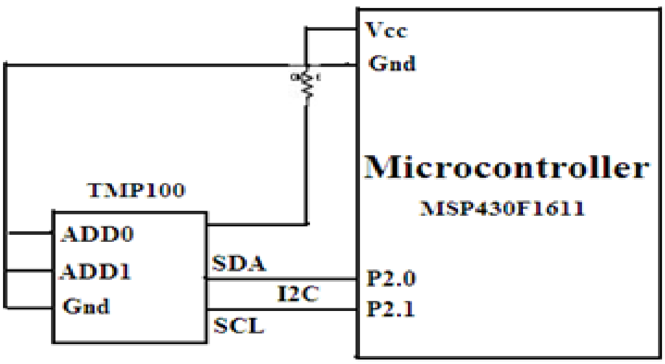

Figure 6. Simple interfacing of Digital temperature sensor

The interest in using this temperature sensor is , when operated in one-shot mode, the TMP100 goes into shutdown mode after each conversion is completed and consumes a typical current of 0.1uA between conversions. This will justify the low power system design [x].

2.4 ZigBee Communication: It provides the low power features of 400 nA SLEEP mode current consumption , Fast startup time: 240 us from SLEEP to RX or TX mode (measured on EM design) , Wake-on-radio functionality for automatic low-power RX polling and Separate 64-byte RX and TX data FIFOs (enables burst mode data transmission). CC2500 can be configured to achieve optimum performance for many different applications. Configuration is done using the SPI interface. The CC2500 is configured via a simple 4-wire SPI compatible interface (SI, SO, SCLK and CSn) where CC2500 is the slave. This interface is also used to read and write buffered data. All transfers on the SPI interface are done most significant bit first. All transactions on the SPI interface start with a header byte containing a R/W bit, a burst access bit (B), and a 6-bit address (A5 – A0).The CSn pin must be kept low during transfers on the SPI bus. If CSn goes high during the transfer of a header byte or during read/write from/to a register, the transfer will becancelled. When CSn is pulled low, the microcontroller must wait until CC2500 SO pin goes low before starting to transfer the header byte. This indicates that the crystal is running. Unless the chip was in the SLEEP or XOFF states, the SO pin will always go low immediately after taking CSn low [xi].

III. Results and Conclusions

The proposed system is designed for low power design and used to study the physiological parameters.A graphical user interface is developed to display the results. As shown in Figure 7 the GUI indicates the ECG pattern ,Temperature of the patient and his pulse rate with respect to time in regular intervals .

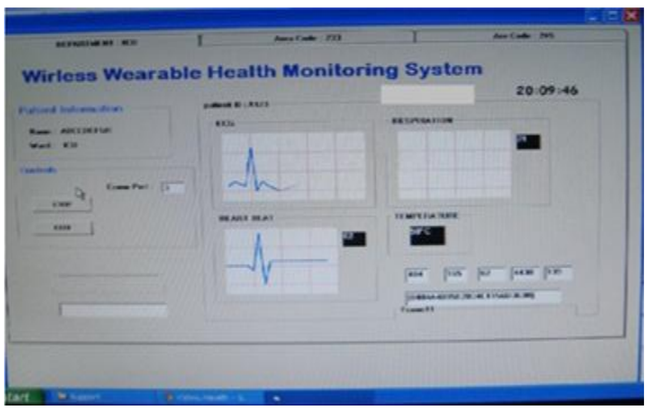

Figure 7. The Graphical User Interface developed

The measurements made by using the present system are compared with tha standard devices available in hospitals and the readings are quite satisfactory. The observations are made on different situations of time and conditions and there is a perfect consistency in the performance of the developed system. The present system is used to measure the ECG and pulse rate and body temperatures of different people and the data is transmitted to remote places by using the wireless sensor module.The ECG sensor leads are taped on the chest ,arm and legs of human body, where the signal is transmitted to a PC for display, further processing and storage. The ECG is sampled around 200 Sample/second. The test human is allowed to move around while ECG is recorded.Figure7 shows the raw ECG waveforms produced using the GUI. It shows the R peak is clearly detectable. The 50 Hz power line interference is also detected in ECG. In the present work , a healthy personal was used to simulate various activities such as sitting, walking, falling and lying on the floor and the information is displayed on PC. The tested subject was sitting, walking, coming down the stairs, walking again and suddenly fall. When lying on the ground, the subject was first lying with face down, then turned to right, face up and finally turned to left. This activity is to capture the orientation of the subject while lying on the ground. The results obtained here are found to be very nearly consistent. In conclusion the Electrocardiogram is the basic tool for cardiac system assessment. Knowledge of ECG needs to be updated frequently as its usage and technical advances are growing .Use of information both from surface and invasive ECG help the anesthesiologist for optimal patient care. MRI, CPB and transport are special situations requiring special attention. Finally ECG should be continuously monitored starting before induction, during positioning, while shifting till after recovery in postoperative care unit [xii].

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