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Low Power Wireless Sensor Node for Medical Application

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Abstract— Recent advancement in wireless communications and micro-electronics technology has enabled development of low cost and low power wireless sensor networks. This paper presents an architectural model of WSN nodes for reliable detection and quick reporting of hazardous events and emergency circumstances that occur in medical cases. The wireless module 'ZigBee' which has the key features like low cost, low power and robustness is used to establish communication between the sensor nodes and main server (Remote system). Sensors connected to node continuously collect data and controller checks the parameter for critical point and if it occurs then it send this information to main server node. Special algorithm is developed called "Alert on Detection of Critical Point" (ADCP). In a mean time wireless node goes to sleep mode for specified duration. This method and low power hardware reduces the power requirement of sensor node.

Keywords— WSN Node, MSP430, ZigBee, ADCP.

I. INTRODUCTION

WSN can be generally described as a network of nodes that cooperatively sense and may control the environment enabling interaction between persons or computers and the surrounding environment [7]. Recent advancement in wireless communications and micro-electronics technology has enabled development of low cost and low power multifunctional sensor nodes that are small in size and communicate within short distance. Sensor network consists of a large number of tiny sensor nodes that are deployed inside the phenomenon or near to it. Sensor node is equipped with a processor, RF transceiver, sensors, peripherals, and power supply unit (battery). All the nodes are monitored and controlled by centralized master node.

Communication can be done using Wireless Local area Networks (WLAN), Bluetooth, ZigBee or Infrared (IR) based on the application [3]. For short distance applications ZigBee is the effective means of communication. WSN technology finds its popular application in medical field, where tiny sensor nodes can be deployed to monitor patient's different health parameter and also used to assist disabled patients.

This work proposed a method and algorithm based on "Alert on Detection of Critical Point" (ADCP). The proposed work consists of monitoring patients' health condition using wireless sensor node. A small operating system integrated with an application program is embedded in the sensor nodes which will take care of sensing (measuring), computing, and communicating with neighbour nodes that gives an administrator the ability to observe and react to events and phenomena in a specified environment [11]. Sensor nodes sense the readings of various biomedical equipments and controller keeps track on each reading for critical point. Depending upon patient's condition and on the basis of age, sex and other parameters, certain range of optimum value of vital sign is determined by Doctor. When clinical parameters are monitored, a difference between test results (values of a continuously monitored parameter) reflects an actual change in the status of the patients' condition. Few vital signs and their optimum values for adults are given in Table 1.

Microcontroller is thus programmed with specific range according to vital sign. If patient's vital signs collected by sensor node exceed or fall below a certain range as specified by doctor, then alert message is generated and this information is communicated to master node. The main idea of our method is the online detection of critical event and scheduling of wake-up activity to alert the doctor to take immediate action in case of emergency. This is particularly useful where a large number of patients are present in a ward and it is difficult for the doctor to keep on monitoring the patients continuously.

TABLE I - Vital signs and their optimum values

Sr. No.	Vital Sign	Optimum Value
1	Blood Pressure	systolic: 90–119 mm Hg, diastolic: 60–79 mm Hg.
2	Oxygen Pressure	6-12 LPM
3	Heart Rate	50 - 90 bpm
4	Body temperature	36.3 - 37.1 °C for males, 36.5 - 37.3 °C for females.
5	Respiratory rate	18–22 breaths per minute

As mentioned above if the patient's vital signs exceed or fall below a certain range and at critical situation only wireless node wakes up and will send alert to remote devices. If vital sign is detected within determined range wireless node goes to sleep mode and it does not send any information to the remote device since information transmission in sensor nodes consumes more power. Only sensors connected to node continuously read data and compare it with normal parameters. The power consumption caused by transmission of one bit of information over 100-metre distance is equivalent to that of the implementation of the 3000 instructions calculation. Thus power consumption is reduced.

Low power consumption is a key factor for ensuring long operating horizons for non-power-fed systems [10]-[11]. In order to increase life duration of WSN by reducing its power consumption, network and system developers need to do modification in the basic WSN architecture. The power management scheme is categorized in two subunits [13]:
1. Network Level -Choice of communication methods and protocols to minimize energy consumption.
2. Device Level – Selection of hardware (components) to achieve low energy consumption in a wireless sensor node.

This research work mainly focus on device level power management. This paper is organized as follows: Section 2 describes the system architecture for the proposed work. Section- 3 describes energy modelling of processor Section-4 describes the wireless transceiver module and technology used. Section 5 describes the design of our novel algorithm based on ADCP for medical application. Other applications are discussed in Section 6. Finally, conclusion is made in Section 7.

II. SYSTEM ARCHITECTURE

The architecture of proposed work is as shown in Figure 1. It consists of a Remote master node and Wireless sensor nodes network. The master node is connected to these entire remote monitoring nodes. To establish communication between the sensor nodes and the master node, ZigBee RF Modules is used. Each node is realized using MSP430 Microcontroller with ZigBee module.

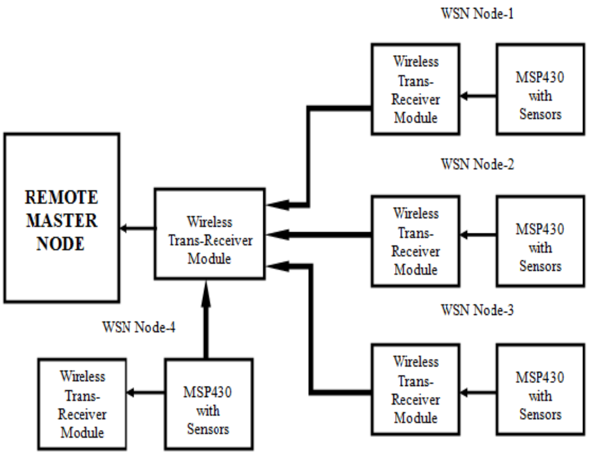

Fig. 1 System Architecture

A remote sensor node consists of four basic components: sensing unit, processing unit (Low power Microcontroller unit), transceiver unit and a power supply unit. Small batteries are used as power source, which is also useful to design portable equipment. The power consumption module in the sensor nodes includes sensor modules, processor modules, wireless transceiver modules. The sensing unit consists of two subunits: sensors and analog-to-digital converters. Compared with traditional data logging systems, it offers two major advantages: it can easily communicate with the rest of the system and it can be re-tasked in the field. The sensors are responsible for monitoring and collection of local information. The processor unit (Microcontroller) is used for the data conversion and control of the entire operation of sensor nodes. Also this unit is responsible for storage and processing of data collected from various sensors, as well as the critical information sent to the master node.

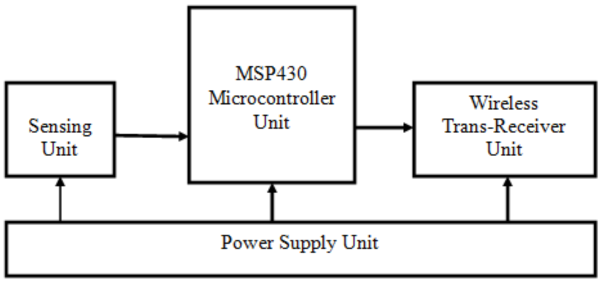

Fig. 2 WSN Nodes

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III. ENERGY MODELLING OF PROCESSOR

Energy Modelling plays a major role for designing an energy efficient WSN [12].The MSP430 family is a 16 bit ultra-low power microcontroller of Texas Instruments, designed specifically for ultra-low-power applications and high performance. Its flexible clocking system, multiple low-power modes, and instant wakeup from leep modes makes this processor more suitable for designing a low power WSN node. It has low power consumption (voltage operation of 1.8V-3.6V) and requires 0.1 micro ampere for Off Mode (RAM Retention), 0.8 micro ampere for real-time clock mode operation, 220 micro ampere /MIPS during active operation at 1 MHz and 0.5 µA in Standby Mode. [5].

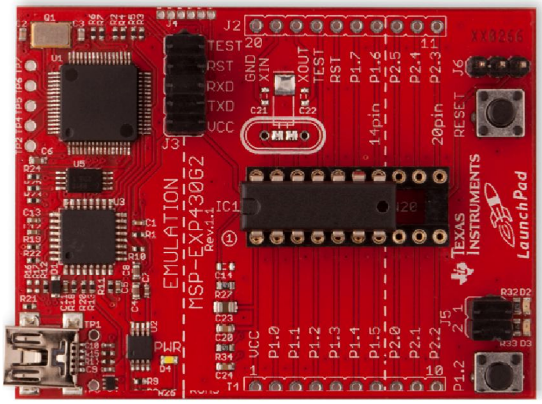

Fig. 3 MSP430G2231 TI Launch Pad System Board

The MSP430G2 TI LaunchPad (Board from Texas Instrument) series microcontroller integrates a large number of external components. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 1 µs. It has 10-bit A/D converter and built-in communication capability using synchronous protocols (SPI or I2C). Typical applications include low-cost sensor systems that capture analog signals, convert them to digital values, and then process the data for display or for transmission to a host system. In terms of operational speed, MSP430G2231 microcontroller can be driven at 16 MHz crystal with 62.5-ns instruction cycle time. The MSP430G2231 has on chip 2KB of flash and 128 Bytes of RAM memory available [5].

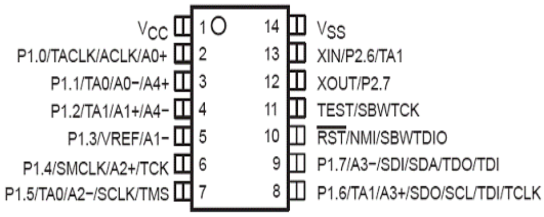

Fig. 4 MSP430G2231 Pin Diagram

The MSP430 family microcontrollers have one Active Mode (AM) and five low-power operating modes which be configured by software based on its application. Five low-power operating modes are LPM0 (low power mode 0), to LPM4. When the MCU need to return to active mode, it can be waken up by an external interrupt signal in less than 1µs. The current consumption in different modes is between 0.1 to 340µA and 1.6µA in standby mode [5]. Under normal circumstances CPU can be placed in the standby mode or in LPM3 mode. Fig 5 presents various operating modes, status of CPU as well as the clock and current consumption of various modes when the MCU is powered by 3 V and 2.2V respectively and runs at 1 MHz [14]. Processor energy consumption (E_{mcu}) is the sum of state energy consumption (E_{se}) and state transition energy consumption (E_{te}) as expressed in Equations 1 and 2.

$$E_{mcu} = E_{se} + E_{te} \quad \ldots\ldots\ldots\ldots(1)$$

$$E_{mcu} = \sum_{i=1}^{n} P_{cs}(i) * T_{cs}(i) + \sum_{j=1}^{n} N_{cc}(j) * E_{cc}(j) \ldots\ldots(2)$$

Where, P_{cs} (i) is the power consumption of the various states of the processor like AM, LPM0 to LPM4 and T(CS) (i) is the time spent during the various CPU states. N_{cc} (j) is the frequency of state transition j and E_{cc} (j) is the energy consumption of one time transition. Fig 5 presents various operating modes, status of CPU as well as the clock and current consumption of various modes when the MCU is powered by 3 V and 2.2V respectively and runs at 1 MHz [13].

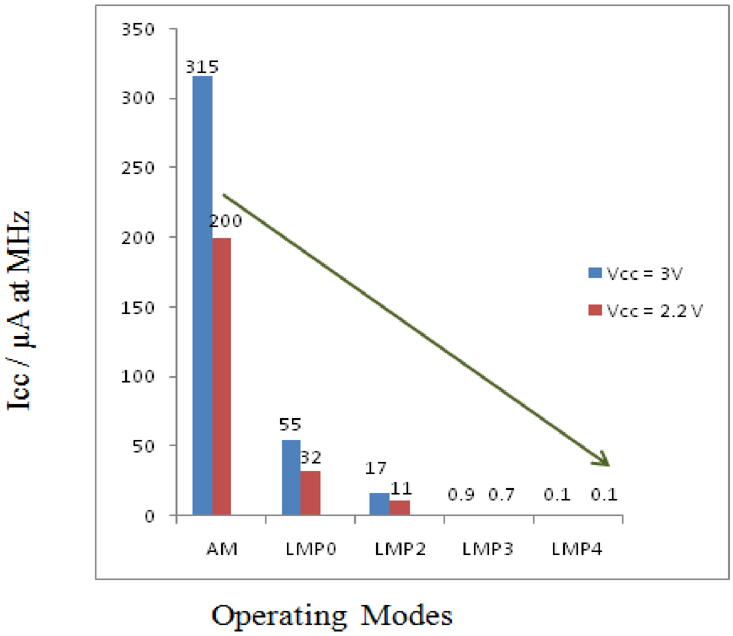

Fig. 5 Current Consumption of MSP430

IV. WIRELESS TRANSRECEIVER MODULE AND TECHNOLOGY

The wireless transceiver module is used to establish communication between the sensor nodes and the master node. Processor and sensor modules have very low power consumption. The majority of power consumptions occur in wireless transceiver module thus it is necessary to use the low power wireless transceiver module.

ZigBee defines the network and application layers above the 802.15.4 [8]. It is the standards-based wireless technology designed to address the unique needs of low-cost, low-power wireless sensor and control networks which can be used almost anywhere, is easy to implement. Here are some facts about ZigBee:

- With hundreds of members around the globe, ZigBee uses the 2.4 GHz radio frequency to deliver a variety of reliable and easy-to-use standards anywhere in the world.
- Consumer, business, government and industrial users rely on a variety of smart and easy-to-use ZigBee standards to gain greater control of everyday activities.
- With reliable wireless performance and battery operation, ZigBee gives the freedom and flexibility for extension.
- ZigBee offers a variety of innovative standards smartly designed to help user in saving cost.

Originally, IEEE 802.15.4 wireless standard was developed for application like remote monitoring and control and its bit rates are specifically limited to 250Kbps (compared to 1Mbps for Bluetooth). The standard defines transmission and reception on the physical radio channel (PHY), and the channel access, PAN (personal area network) maintenance, and data transport (MAC). Actually, ZigBee is a combination of the wireless standard called Home RF-Lite and the 802.15.4 specification. It operates in the 2.4GHz radio band (the same band as the 802.11b standard, microwaves and cordless phones) over 16 channels. It is capable of connecting 255 nodes per network at speeds of up to 250Kbps at a range of up to 30 meters. The ZigBee protocol aim to provide longer battery life (months/years on a single battery charge) and to be a lower-cost solution for wireless sensing, remote monitoring and control applications. ZigBee uses mesh networking (peer-to-peer) to provide redundancy for unattended system operation and reliability.

In mesh networks each node has a low-power transmitter and communicates directly only with neighboring nodes and these latter nodes relay the data to more distant nodes. If a link becomes congested or a node fails, the mesh automatically redirects data packets via an alternative path. This characteristic makes mesh networks virtually immune to localized interference such as that caused by motors turning on or arc welders. Mesh networking aids unattended system operation while the star topology used in cell phones and wireless LANs has a central control point that requires physical movement to improve connectivity. The foundation of every ZigBee standard and specification is the powerful IEEE 802.15.4 physical radio standard operating in unlicensed bands worldwide at 2.4GHz (global), 915 MHz (Americas) and 868 MHz (Europe). It delivers raw data throughput rates of 250Kbs at 2.4GHz (16 channels), 40Kbs at 915MHz (10 channels) and 20Kbs at 868MHz (1 channel). Transmission distances are remarkable for a low-power solution, ranging from 10 to 1,600 meters, depending on power output and environmental conditions, such as other buildings, interior wall types and geographic topology. Standing on top of 802.15.4 (Refer figure 5 above), ZigBee defines the topology management, MAC management, routing, discovery protocol, and security management, and includes the 802.15.4 portions. ZigBee is designed to work in either the 868-928 MHz band to cope with regional differences, or 2.4 GHz ISM

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band (typically available worldwide). The system requirements Bluetooth and other wireless protocols. ZigBee's bandwidth is slower than Bluetooth, but the range **is** greater and the number of nodes is much greater - 255 (Bluetooth is limited to 8 nodes per network).

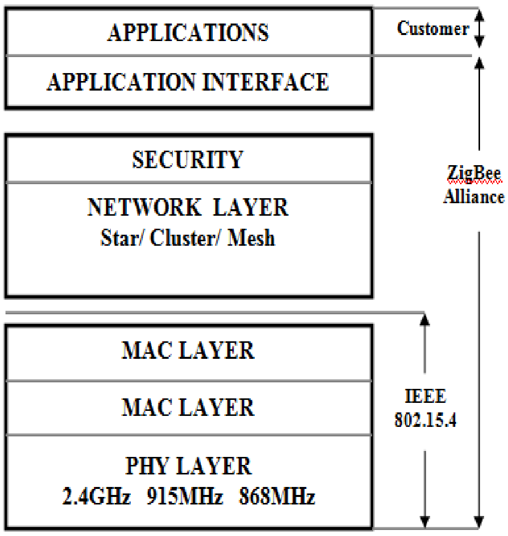

Fig. 6 Protocol stack features

The protocol stack for IEEE 802.15.4 and ZigBee may use a cost-effective. 16-bit RISC Architecture microcontroller (MSP430-based) to provide the silicon hardware and run the software. The full stack is less than 32 Kbytes, while a simple node-only stack can be 4-6 Kbytes.

ZigBee networks are primarily intended for low duty cycle sensor networks (<1%). A new network node may be recognized and associated in about 30ms. Waking up a sleeping node takes about 15 ms, as does accessing a channel and transmitting data. ZigBee applications benefit from the ability to quickly attach information, detach, and go to sleep, which results in low power consumption and extended battery life.

There are three types of nodes: Coordinator (ZC), Router (ZR), and End Device (ZED), defined in ZigBee NWK layer [2], which is responsible for starting and maintaining a network, configuring a device, addressing, synchronizing in a network security and routing. The ZC acts as the sink of standard WSN. An implementation of a WSN for text data transmission using Bluetooth has been proposed by Soo-Hwan Choi. However, this approach has several limitations – high cost and power consumption, longer latency, and low density of nodes. On the other hand, by comparing the key features of ZigBee and Bluetooth, it can be found that, as shown in Table 2, ZigBee is clearly much more appropriate than Bluetooth. Therefore, we propose a novel approach for design of WSN for medical application using ZigBee.

TABLE II- Comparison between ZigBee and Bluetooth

Sr. No.	Feature(S)	Bluetooth	ZigBee
1	Power Profile	Days	Years
2	Complexity	Complex	Simple
3	Nodes/Master	7	64000
4	Latency	Enumeration up to 10 Seconds	Enumeration up to 30ms
5	Range	10m	70m-300m
6	Extendibility	NO	YES
7	Data Rate	1Mbps	250Kbps
8	Security	64-bit, 128-bit	128-bit AES and Application Layer user defined

V. ALGORITHM USED

A novel approach ADCP (Alert on Detection of Critical Point) is used in this particular application. As discussed above this particular application is developed to provide alert based on some critical point. For example: An SaO2 (arterial oxygen saturation) value below 90% causes hypoxemia, a SaO2 below 60% indicates that the body is in lack of oxygen, This measurement is often used to get an idea of how much flow the patient needs to stay healthy. A slow heart rate, defined below 60 bpm and is a fast heart rate, defined as above 100 bpm at rest. Respiratory rate for a healthy adult at rest is 12–15 breaths per minute. The typical oral measurement is 36.8° ± 0.4°C (98.2° ± 0.7°F). 41 °C (106 °F) -32 °C (90 °F) is a critical body temperature leads to emergency. Based on this information critical point is set considering percentage of tolerance of vital sign. The following Figure 7 shows flow chart of how above mentioned WSN node operates at the place where it is deployed.

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```
Initialize Sensing module ();
Initialize ports;
Collect data (N) from sensor unit;
Initialize Processing module ();
If (CPU is disabled && MCLK and SMCLK disabled
 && DCO's dc generator disabled && ACLK active)
{
Low-power mode 3 (LPM3) enabled;
{
Compare N with standard value;
If (N /= standard value)
{
Switch to active mode;
Initialize transreceiver module ();
Send alert message (….N…..  );
        Turn of transreceiver module ();
         Switch to Low-power mode 3 (LPM3),
        }
        Else
        {
        Compare another parameter X;
        Check conditions;
         }
 }
 }
```

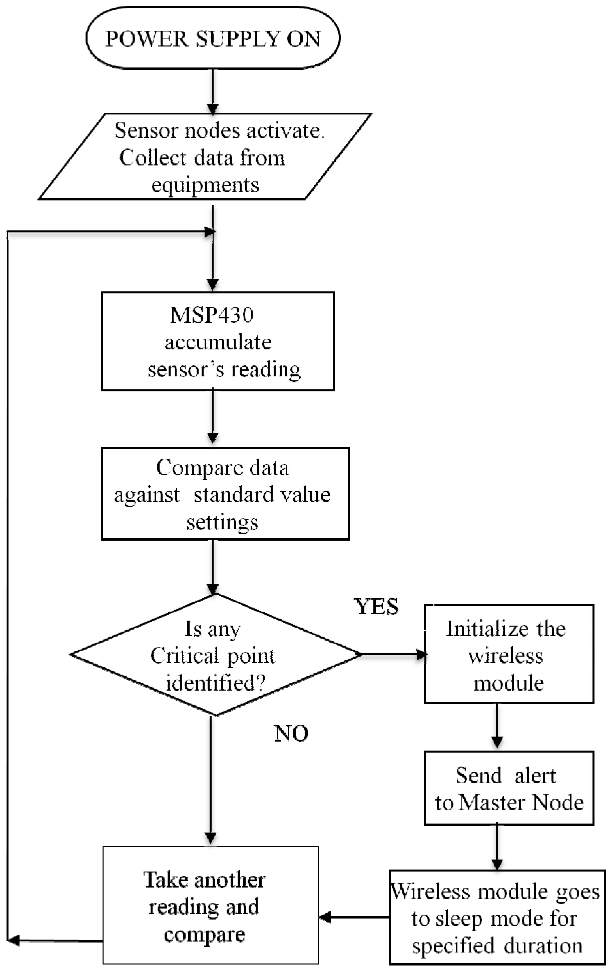

Fig. 7 Flow Chart for Algorithm.

VI. APPLICATIONS

The above module can be used in hospitals for monitoring the vital signs of patients, such as blood pressure, temperature, pulse rate; oxygen pressure etc. Generally critical incidence occurs in medical area, industrial area, commercial chemical plant where continuously monitoring is not feasible. This system can also be installed in various industries to monitor optimum physical conditions. For example, in cotton industries, it can be used to monitor humidity level. The information so monitored can be transmitted to remote locations to initiate appropriate action on time.

VII. CONCLUSION

In this paper we presented a cost effective method of monitoring patient's health parameters remotely which help in reducing chances of pain and discomfort of patients for longer duration. A low power implementation for wireless sensor networks node using low power MSP430 microcontroller and novel ADCP algorithm is presented. Wireless sensor networks are utilized in many applications. This design has the features of low cost and low power which allows its use in many applications where more than thousand nodes are deployed. We have proposed an automated system that shows vitals of patient and alert doctor in case of emergencies.

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