Design of a Low Power Wireless Sensor Node for Environmental Monitoring

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Abstract — **In recent years, the interest in Wireless Sensor Network(WSN) has been growing dramatically. To meet this trend, a low power WSN mote, using MSP430 micro-controller and ADF7020 radio chip, was designed to carry out building energy management and environmental monitoring. In this paper a practical design procedure of the mote, including schematic, layout design and software programming, is provided and the mote board is shown. The mote utilized multi-layer architecture of power layer, wireless layer and sensor layer to enable flexibility. Temperature and relative humidity were measured and transmitted wirelessly. Furthermore, the mote had achieved low power consumption because of the use of the sleep mode of the micro-controller and turning off the radio during idle.**

Keywords — **Wireless Sensor Node Design, Energy Consumption, Building Environmental Monitoring, Temperature & Humidity Measurement.**

I Introduction

A wireless sensor network (WSN) usually consists of micro-controller, radio frequency transceiver, and sensor board and power source [1]. A WSN node's functionality is determined by the micro-controller, which operates the sensor to sample data by various commands.

Technological advances in areas like computing platform miniaturization, low power radio transceivers and network self-organization protocols have enabled the development of small, non-intrusive and configurable sensor platforms, which last for significant mount of time with very limited power supplies, and form an information sampling network [2]. WSN acts as a key factor in the relationship between digital and analogue world, not only because of the sensor technology, but also the implementation of sensor networks. Size and energy consumption are the most important factors for WSN platform [3]. It is challenging to provide long term power supply since the WSN mote is usually powered by battery. Thus the power supply is a critical issue of the WSN mote.

A case study showed that 15-20% of the energy consumption can be reduced when BEEM (building energy and environmental monitoring) system was successfully implemented [4]. However, there were several problems for WSN in building energy management. It is complex and difficult to install a vast number of sensors into buildings and the cost of maintenance makes them less popular [5].

Nowadays, the combination of environmental study and wireless sensor network (WSN) has become more and more popular in the relevant research field. With the demand of environment and building monitoring, the applications of WSN have been developed with desired functionality. In this paper, a low power consumption solution is designed for environmental monitoring, using ultra low power radio chip ADF7020 and micro-controller MSP430.

II System Architecture

The build-up structure, shown in Fig. 1, for the proposed WSN mote mainly consists of sensor layer, power supply layer and control layer.

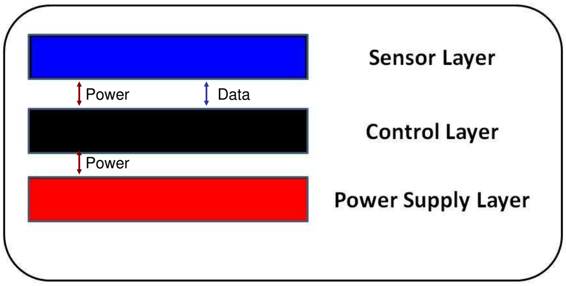

Fig. 1: Build-up Layers

Table 1: Comparison of Two Micro-controllers

Features	ATMEGA1281	MSP430F5437
Power Supply	2.7V-5.5V	2.2V-3.6V
Active Mode (3.3V)	500μA/MHz	312μA/MHz
Wake-Up Time	6μs	less than 5μs
Flash	128KB	256KB
CPU	8-bit RISC	16-bit RISC
Interrupts	48	64
Timer/Counter	2x8-bit timers	3x16-bit timers
ADCs	8	14

As regards to sensor layer, temperature, humidity sensor, PIR sensor and photodiode sensor could be placed for measurements in buildings. In terms of power supply layer, a LI-ON battery is connected to power plane, supplying the mote by the connectors. The control layer consists of two main chips which were MSP430F5437 and ADF7020 radio transceiver. The build-up structure is flexible and compatible with other motes or layers without re-design since all the layers follow the same pin definition on the connectors for power supply and signals.

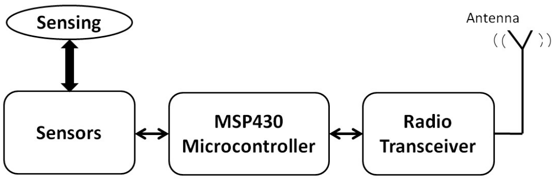

Fig. 2: System Diagram

The system diagram is shown in Fig.2. For the proposed ADF7020 mote, the desired sensor such as SHT1x temp &humidity sensor, is connected to control layer by the 40-way and 80-way connectors, and the mote can be programmed by SPY-BI-WIRE interface with desired function. The sensor unit will receive the commands from MSP430 micro-controller to measure data, which will be then sent to MSP430 micro-controller. Once the MSP430 receives the data, it will transmit to gateway wirelessly by radio transceiver.

From the micro-controller consideration, a lower energy cost but powerful solution is quite helpful. MSP430 provides lots of advantages compared to some other popular micro-controller, for example Atmega AVR. Table 1 illustrates that MSP430 costs less power (voltage and current), has more resources(Flash and ADC, Timer), and is faster than other micro-controllers. That's why MSP430 was chosen as the control unit for the WSN mote in this paper.

Table 2 also shows the parameter comparison

Table 2: Comparison of Two Transceivers

Features	CC2420	ADF7020
Frequency	2.4GHz	433MHz
Power Supply	2.1V-3.6V	2.3V-3.6V
Current Consumption (Transmit)	17.4mA (0dBm)	13mA (0dBm)

of ISM band chip ADF7020 and Zigbee radio chip CC2420. ADF7020 consumes less power than CC2420. More importantly for the housing monitoring application, ADF7020, working on 433MHz and 868MHz, could transmit further than Zigbee of 2.4GHz with the same transmission power.

III Interface Definition and PCB Design

After the description of the system and selection of the chips in the previous chapter, the design procedure and some practical considerations are given in three steps: interface definition, PCB schematic and layout desgin.

a) Interface:

Fig. 3 shows the interface definition between chips and PC. I^2C was used for communication between the sensors and the micro-controller, while the micro-controller utilized SPI to connect the radio. PC, however, received data from micro-controller by UART.

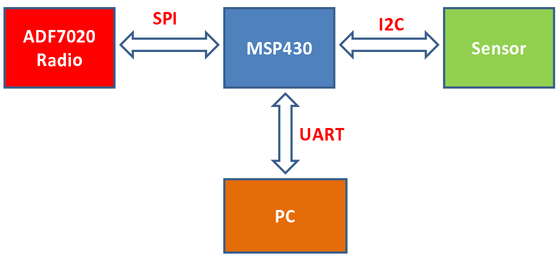

Fig. 3: Interface definition of the mote

I^2C only uses two bidirectional open-drain lines,

Table 3: Spy-bi-Wire JTAG programming interface

Device Signal	Direction	Function
TEST/SBWTCK	IN	CLOCK Input
RST/NMI/ SBWTDIO	IN,OUT	Data Input/ Output
VCC		Power Supply
VSS		Ground Supply

serial data line (SDA) and serial clock (SCL) and pull-up resistors. Every device connected to main bus can be classified by its own address and the master-slave relationship is formed. The master can be transmitter or receiver. The main bus can connect many master devices; if two or more master devices send data at the same time, the conflicts check can avoid such problem.

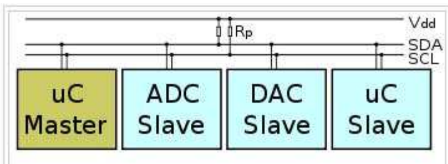

Fig. 4: I^{2}C interface

SPI is the abbreviation of serial peripheral interface bus. The SPI bus is a synchronous serial data link standard invented by Motorola, which operates full-duplex mode. It consists of four lines, SCLK (serial clock, output from master), MOSI (master output slave input, output from master), MISO (master input slave output, output from slave) and SS (slave select, output from master).

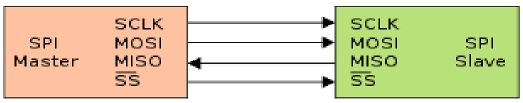

Fig. 5: SPI interface

UART is a universal serial data bus for asynchronous communication. The bidirectional communication can be used as full duplex transmission and receive. First of all, UART converts the received parallel data to serial data transmission. Data frame starts from a low start bit and ends by eight data bits. When the receiver detects the start bit data ready, it will send the data and try to work with sender's clock frequency synchronization. Data transmitting can start from either LSB or MSB.

The TEST/SBWTCK pin-out is used to enable the JTAG signals. In addition to these signals, the RST/NMI/SBWTDIO is required to interface with MSP430 development tools and device programmers. The JTAG pin definitions are shown in Table 3.

b) Schematic Design:

Two external crystals (32.768 KHz and 8 MHz) were implemented. The 8 MHz clock is used for high processing speed application such as ADCs, while 32.768 KHz will be applied for peripherals to save power. I^{2}C, SPI and UART pinout were available in the MSP430 micro-controller schematic design.

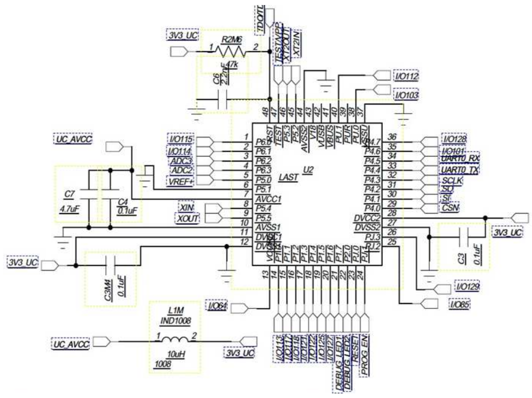

Fig. 6: MSP430 schematic

c) Layout Design:

External SMA connector is used by Tyndall 25mm * 25mm WSN motes. The PCB has six layers: top and bottom layers for signal processing, power and ground layers, and two inner layers. The substrate material is FR-4 epoxy. Some extra Vias were used to reduce the parasitic coupling.

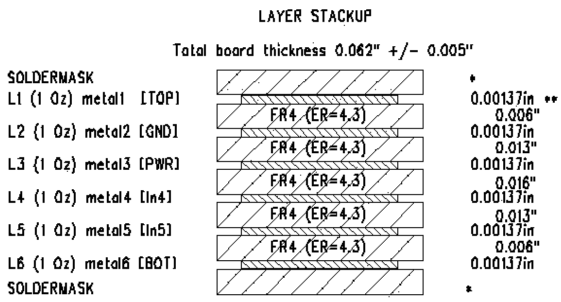

Fig. 7: PCB Layout Stackup

The total thickness of the PCB was 0.062 inch.

IV Software Programming

I^{2}C: In this paper, SHT1x temp&humidity sensor of Senserion Company was implemented for programming and testing. The sensor unit utilized non-standard I^2C interface.

The non-standard I^2C interface sequence included a transmission-start command, temperature or humidity measurement commands and acknowledgement. The digital output of temperature is a 14-bit binary value while relative humidity is 12-bit. The equations for temperature and relative humidity have to implement to the relevant equations as following:

Relative Humidity:
$RH_{(Linear)} = C_1 + C_2 + C_3 * SO_{RH}^2 (\%RH)$
where SO_{RH} is 12bit value, $C_1 = -2, C_2 = 0.0367, C_3 = 1.5955 * 10^{-6}$

Temperature:
$T = d_1 + d_2 * SO_T$
where $d_1 = -40, d_2 = 0.01$, VDD is 3.3V and SO_T is 14bit value[6].

The non-standard I^2C interface, supporting only one device, ultilized two general-purpose I/Os as I^2C data line and clock line. Because of that, the subsequent command consists of three address bits (Only ′000′ is supported) and five command bits. The SHT1x indicates the proper reception of a command by pulling the DATA pin low (ACK bit) after the falling edge of the 8th SCK clock. The DATA line is released (and goes high) after the falling edge of the 9th SCK clock. From the datasheet, command of measuring temperature was code 0000 0011 and command of measuring relative humidity was 0000 0101. There was a figure showed the example of relative humidity measurement sequence in datasheet.

SPI: The SPI interface processing was divided into two sections. The first was transmitting section and the second was receiving. The steps were similar to the I^2C interface. The definitions of the measurement of temperature and humidity need to be introduced as well. Meanwhile, the I^2C code of sending command to sensor unit was included as well.

Interrupts and sleep mode: The sleep mode is important for WSN mote to save power during the period the chips are not working. The system working cycle is presented in Fig. 3. After certain mount time of sleep mode, the timer wakes up the micro-controller. The micro-controller sends commands to the sensor to start sampling the data. Then the collected data is processed and transmitted by radio. The micro-controller will turn off the radio and sensor after the transmission is finished and switch to sleep mode for the next cycle. With the help of interrupts and sleep mode, total energy consumption is significantly reduced.

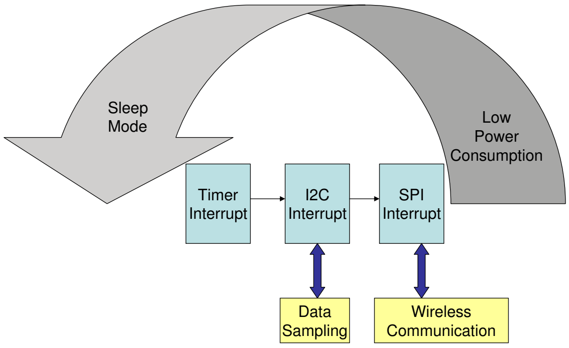

Fig. 8: System Working Cycle

V Measurements of Temperature and Humidity

Fig.9 and 10 illustrate the measurements of temperature and relative humidity value. In terms of temperature, the test was carried out in different environments including fridge, living room, kitchen and central heating which had a temperature range from 0 degree to 50 degree. During the temperature testing, the sensor unit showed the value of less than 5% error rate. As regards to the relative humidity, the test was performed in time scale of one day from 9 O'clock morning to 3 O'clock afternoon. The comparison between real value and the sampled relative humidity had less than 5% bias, which was acceptable.

Once the sensor values were verified, the wireless transmitting between the mote and the received base station was carried out. The base station received the data wirelessly from the mote and the data was shown on computers.

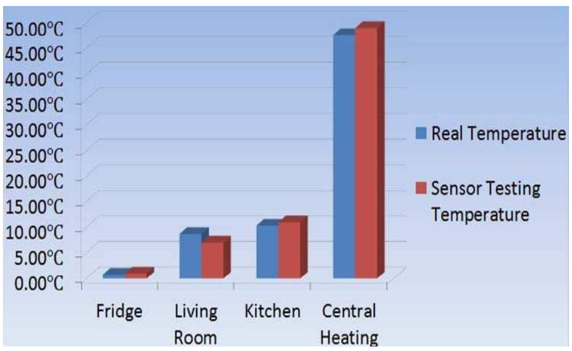

Fig. 9: Temperature Measurements

Power Consumption is another factor to be critical in environmental monitoring for a reliable battery lifetime. The power consumption during wireless communication is provided in Fig. 11. The voltage in Fig. 11 was measured on an one ohm resistor on the power bus and thus represented the level of the total current consumption. The voltage

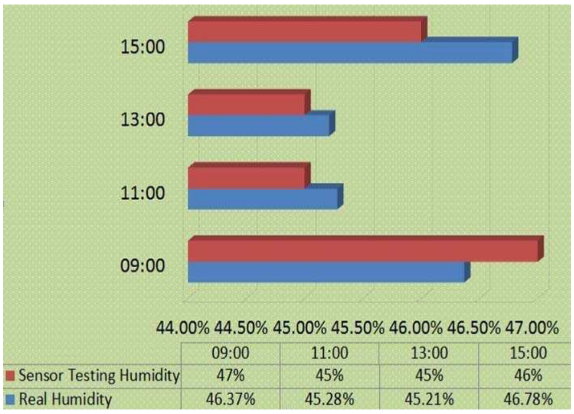

Fig. 10: Relative Humidity Measurements

supply of the system was 3.3V.

It is clear to see that the current during sleep mode is very low to be the level of 100 μA. Then there is a 2ms period of wake up time, consuming 7mA in average. During the later 35ms transmission time, the average current is 18mA (0dBm).

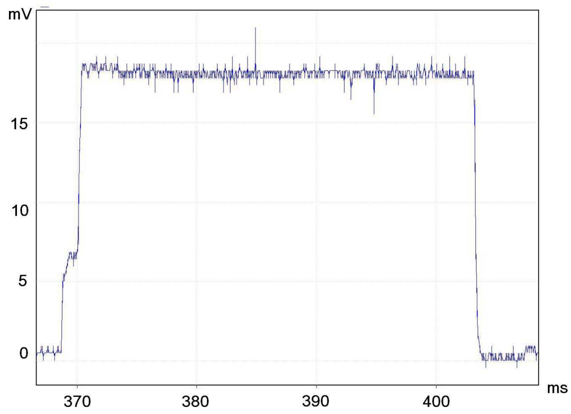

Fig. 11: Power Consumption During Data Transmission

VI Summary

A low power consumption wireless sensor mote, with MSP430 micro-controller and ADF7020 radio, is developed for environmental monitoring. The mote was designed by PADS and programming by CCS in C. The mote samples temperature and humidity measurements with the onboard sensor. The results of the measurements are precise compared with the reference values. Meanwhile, the mote could transmit and receive the data by ISM ban ADF7020 radio chip. The peak current consumption is as low as 18mA for 0dBm transmission power and 3.3v power supply.

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