ZIGBEE COMMUNICATION WHEN BUILDING A BODY SENSOR NETWORK FOR ELDERLY PEOPLE

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***Abstract*—Due to the needs of services to support people with incapacities or reduced mobility, designing wearable and non invasive monitoring devices for them is an interesting technical research objective, which can effectively be reached using wireless communication. This work is focused on the development of a system for measuring the human movement using devices that sense accelerations and angular rates, broadcasting the information through the networked nodes with the ZigBee wireless communication standard.**

I. INTRODUCTION

In order to track accurately the movement of the human body more than one sensor is needed to obtain the gait, posture and articulations position [1]. As an example, two biaxial accelerometers sensor nodes are needed, at least, for measuring knee angles, placed at each link of the articulation [2]. By increasing the number of sensors, the knowledge of the activity that is being monitored can be improved [3].

Measured data can be processed either off-line or on-line. In off-line mode, data gathered by the network is stored in a memory device for later processing. In on-line processing mode, however, the system is able for feedback information to the user for improving, as an instance; his/her balance and reduce the risk of falls. Main challenge for this operation mode is processing data and obtaining useful indications in real time, because it will need enough processing power for implementing pattern recognition methods on placed devices.

Another constraint to is that sensor nodes should be capable of sending captured data in real time (or near real time) with a rate of signal acquisition high enough to be useful for motion monitoring. This rate is usually set above 30 samples per second[4]. The number of networked nodes required to monitor different activity parameters for human movement are in the range from 2 to 9 nodes.

The last requirement to be considered is power consumption. Since nodes should be wearable and mobile, so they are self-powered by a battery and power consumptions must be reduced at maximum to be operative as long time as possible.

Many wireless protocols exist, in Table 1 is presented a brief comparison, being ZigBee technology the one that is closer to the before mentioned requirements for our monitoring system.

II. ZIGBEE COMMUNICATION NETWORK

ZigBee is a low cost and low power consumption radio communication solution based on the IEEE 802.15.4 WPAN (wireless personal area networks) [5]. The main features of ZigBee are[6]:

	ZigBee 802.15.4	GSM /GPRS	Wi-Fi 802.11b	Bluetooth 802.15.1
Network size	2^64	1	32	7
Range (meters)	1-100+	1000+	1-100	1-10
Bandwidth (KB/s)	20-250	64-128	11.000+	720
System resources	4-32KB	16MB	1MB+	250KB+
Battery life(days)	100-1000+	1-7	0.5-5	1-7

Table1. Network comparison

- Low power – Devices can typically operate for long periods on AA type batteries using suitable duty cycles.
- Low data rate – The 2.54 GHz band supports a radio data rate of 250 kbps. Actual sustainable traffic through the network for sampling and monitoring applications is lower than this theoretical radio capacity.
- Small and large networks – ZigBee networks' size vary from several devices to thousands of devices communicating seamlessly. The networking layer is designed with several different data transfer mechanisms (types of messages) to optimize the network operation based on the expected use.
- Range – Typical devices provide sufficient range to cover a normal home and readily available designs with power amplifiers extend the range substantially. A distributed spread spectrum is used at the physical layer to be more immune to interference.
- Simple network installation, start up and operation – The ZigBee standard supports several network topologies and the simple protocols for forming and joining networks allow systems to

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self configure and fix routing problems as they occur.

III. Device Components

Each device node is build on two modules: a processing module, and a RCM (Radio Communication Module) plus signal acquisition.

A. Radio Communication RCM EM250

The RCM used in this work is the Ember's EM250 [7]. The EM250 chip consist of a 2,4GHz radio transceiver, a XAP2b microprocessor, flash and RAM memory and typical micro controller peripherals like ADC, SPI, and UART ports. The EM250 chip is mounted on a RCM board that can be used as a embedded node by itself.

B. DSPic Micro controller

The processing module includes a Microchip DSPic30 micro controller with the functionalities of a 16 bits micro and the possessing power of a DSP in a single package, thus enabling single cycle of operation, DSP function giving a greater processing power than a simple micro controller. Using the C30 compiler programming can be performed in C code, simplifying code generation.
The DSPic model selected from the 30f instrumentation group family is the p30F3012 one, since its small package (18 pins) helps to reduce the size of the prototype.

C. Used Sensors

The signal acquisition module attached to the RCM includes three kinds of inertial sensors:

1) H48C module

The H48C module from Parallax holds a Hitachi H48C triaxial accelerometer, a signal conditioning circuit and a MCP3204 ADC with digital SPI interface, and a voltage regulator powering the devices at 3.3V. The measuring range of the sensor is +/-3g in the XYZ axis. The converter resolution is 12 bits.

2) ADXL203 chip

The ADXL203 chip is a high precision and low power consumption analogical accelerometer, measuring dynamic and static accelerations up to +/- 1.7G in the X and Y axes. In order to get signal for the 3 axis, two of those integrated circuits are needed, one of them placed perpendicularly to the printed board.

3) Murata Gyrostar

The gyroscope Murata Gyrostar measures the angular velocity. The response of this sensor is linear up to an angular rate of 300 degree/second.

IV. Device Modules

Two different modules have been designed:

A. SPI Sensing + Communication Module

Due to the capacities of the EM250 ADC (low voltage reference), sensor data in the EM250 controller is obtained from the sensor sub-module using digital serial interfaces SPI. The circuit board has two low drop out voltage regulators to provide the power to the parallax module and RCM, it holds the 28 pin connector with power and SPI signals and a connector to the H48C module.

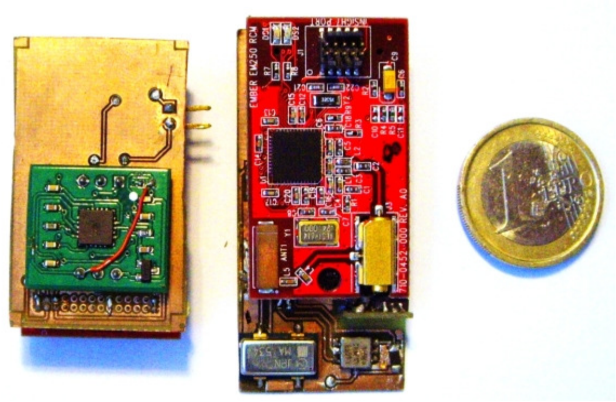

Fig. 1 The SPI Sensor Module, The DSPic sensor module + EM250 RCM, and a euro coin as size reference.

B. DSPic Module

The DSPic based processing module is a versatile and powerful data acquisition unit. This module is based on a printed board that holds the voltage regulators to power the DSPic, the RCM, the two ADXL203 accelerometers and one Murata gyroscope. The board has a 28 pin connector that provides power and digital SPI signals to the EM250 RCM.

V. Programming

The network topology used is a star network: the data flow is mainly oriented from the sensor nodes to the coordinator one and data is gathered in a PC as is shown in Figure 2 . In order to lower the power consumption of the system, the devices are configured as Sleepy End Devices, so that this nodes' operation time can last longer. This type of configuration enables the sensor nodes to turn off the radio while not sending/receiving data, however they cannot receive data directly but asking to a network coordinator if there are messages directed to them. For our case there is only one network father, the coordinator node, so not much bandwidth is lost while lowering the power consumption.

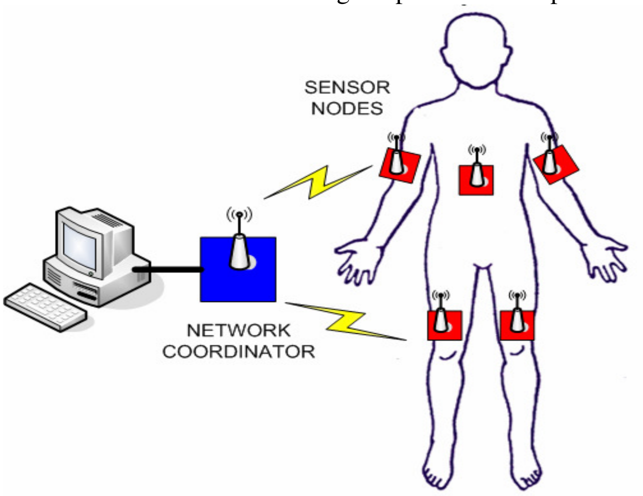

Fig. 2 Network topology and data flow

A. Method for time synchronization

In order to enable the data processing from different sensor nodes to extract relative measurements, like the angle between two segments of a articulation using two sensor nodes, the data required to perform these calculations needs to be as closer as possible in the same time reference, hence the time of measurement is sent inside the data message.

A common time reference between networked devices is obtained through a time synchronization method. The time reference is fixed to be the timer of the coordinator node: the sensor nodes get this time from a multicast time message, they compare this time with its own timer and the difference is the offset that is added while sending the time of measured data referenced in a common base time. In order to get the minimum latency during the time synchronization, the coordinator sends a message to all the networked nodes to stop sending messages and it leaves the radio channel free, then the multicast time synchronization is sent using a multicast message that reaches the nodes at the same time. The synchronization process takes about 5 seconds to be completed; during this period no sensor data is sent for avoiding timer drifts.

B. Coordinator Node Program

The coordinator node is a device that initializes the network, manages the process of joining or leaving the network for the other network devices, and, in the case that security is enabled, it will act as trust centre assigning crypto-keys. While the network is formed this node will act as a master of the network by performing the synchronization and controlling the state of the sensor nodes function modes from sleeping, sending data and awaiting synchronization message. The sensor readings are sent trough UART to a monitoring application.

C. Sensor Node Program

The sensor node makes a join request to the coordinator the network, once connected enters in 'synchronization mode', when it gets the time synchronization message leaves the network; then joins the network again as a sleepy end device which can turn off the radio to save energy but still can receive radio messages thanks to the coordinator node that acts as a postman.

There are two types of sensor nodes: one of them gets the data from a DSPic while the other gets the data from a accelerometer module, the hardware of these nodes being different but the software is quite similar, besides the part of data gathering.

1) Data acquisitions from DSPic

The RCM remains in sleep mode awaiting a digital signal that warn it about data is coming from the UART; then it sends the data and continues in sleeping mode.

2) Data acquisition from SPI

In this case it doesn’t completely sleeps because it must read data from the SPI at regular intervals. While not reading, it shut down the peripherals and waits for a timer interruption to go on reading, once the message is full, it is sent to coordinator.

D. DSPic Program

The DSPic program initializes its peripherals, next it changes to 'measuring mode' by reading ADC buffer at regular intervals and finally it uses a digital line for waking up the RCM, sending the data trough UART and so on.

E. Data Bandwidth

The full theoretical bandwidth is 250Kbps, but due to some reasons, the practical number of messages per second is 65 (60Kbps). The main reason for the difference between the maximum theoretical and practical bandwidth is that the coordinator node is performing many tasks besides receiving wireless data, like data managing and data sending to a serial port. The mode of communication configured in the sleepy sensor nodes is 'APS no reply', enabling a better power saving, but limiting the effective practical bandwidth.

There are other options that modify the theoretical bandwidth value: ZigBee implements a message encryption, the message is encrypted using a 128 bits AES network key moreover this encryption is implemented using a hardware encryption coprocessor in order to not overload the main processor. Enabling security takes 18 bytes from the message payload so it lowers the effective bandwidth.

In short, the rate of messages per second in our network configuration is 60 (MAC 55.6Kbps, payload 40Kbps). Trying to send more than this message rate leads to lost messages and a bandwidth reduction.

The maximum number of SPI nodes in our network is 12 because the triaxial sample is 6 By long, a security enabled message can hold 12 samples and a 4 By time reference data, and the accelerometer signal data rate is 60Hz.

The maximum number of DSPic nodes in our network is 9 because the triaxial and one gyro sample is 8 By long, a security enabled message can hold 9 samples and a 4 By time reference data, and the accelerometer signal data rate is 60Hz.Hence, in order to maintain the signal acquisition rate the network can hold 9 dsPIC nodes or 12 SPI sensor nodes, or a combination of sensor that not go over the 60 messages per second practical limit.

An important remark is that this available bandwidth is shared by the devices using the same radio channel, and there are 16 available channels in the 2.4GHz band [6], so if there is another ZigBee network or any other radio device in the same radio frequency and into the range of our network, it can cause a drop in the available bandwidth. In this case, the coordinator sends a message to the nodes to leaving the network, it searches a free channel and then the sleepy nodes find their coordinator and the process starts again.

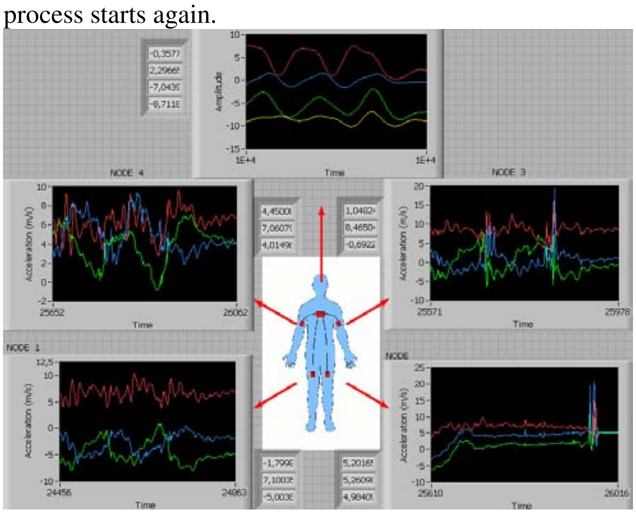

Fig.3 Acquisition Program caption

F. LabView Interface

The user interface is a LabView program running on a PC, but with some modifications it could also run on a PDA. This program reads the serial port RS-232 and displays the accelerations of each sensor node in a graph, it stores the data received in an individual text file for each sensor node.

VI.POWER CONSUMPTION

One of the objectives in the work that has been kept in mind during all the design process is to achieve low power consumption while maintaining a relatively high data acquisition-transmission rate. To measure the power consumption a 1Ω resistor is placed in serial with one of the voltage source wires, next the voltage between the resistor terminals is measured with an oscilloscope and the obtained average is proportional of the current consumption. The results of these measures are shown in Table 2.

The power consumption of the EM250 nodes is largely determined by the number of messages per second; the radio can have 35-42 mA consumptions spikes in sleepy nodes (radio power output is adjustable); while not sending the radio is turned off and the device is set to low power mode, since 'deep sleep' took too long to wake up and would not maintain the data rate, meanwhile the coordinator node uses 35 mA all the time.

Description	VCC(V)	ICC(mA)	Power (mW)
Coordinator node	3	35,54	**106,6**
H48C module alone	3	5,33	**26,6**
EM250 sending 13,6 dummy Messages/s	3	11,9	**35,9**
EM250+H48C sending 13,61 Messages/s	5,2	18,12	**94,22**
EM250+H48C sleeping	5,2	5,02	**35,9**
DSPic board reading 144 Hz	5,2	21,23	**110,40**
DSPic board + EM250 sending16 Messages/s	5,2	35,41	**184,132**
DSPic node EM250 sleep	5,2	23,32	**121,264**

Table 2 Power consumption table

The SPI sensor node consumes 94mW, while the DSPic node 184mW, this difference being due to the larger consumption of the DSPic processor and the Gyroscope.

VII. CONCLUSIONS

This paper shows the success on implementing a wireless sensing system for human movement monitoring. Once the technology has been selected, the system design and implementation is explained.
The objective about low power consumption has lead to a synchronization scheme necessary to maintain common baseline timing in a network where nodes are not usually listening to the radio for saving up to 35 mA.

The bandwidth required in this application is quite close at the theoretical bandwidth, and even closer at the practical one when the sensor nodes had more axis to measure and they send their lectures the number of nodes of the network would be reduced, a possible solution is to process the data inside the sensor nodes in order to reduce the data send, or even only send the data when a threshold or action is detected, this would lead to a event driven communication that would allow more nodes in the network.

The design can be improved by selecting stand alone SPI accelerometers that will use less power than the H48C module. The electronic board can be improved by optimization its size and voltage regulator features.

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