Wireless Sensor Network Deployment for Building Environmental Monitoring and Control

Essa Jafer[1], Rostislav Spinar[2], Paul Stack[3], Cian O'Mathuna[1], and Dirk Pesch[2]

[1] Tyndall national Institute, Lee Maltings, Prospect Row, Cork, Ireland
[2] Cork Institute of technology (CIT), Cork, Ireland
[3] Department of Civil and Environmental Engineering, University College Cork (UCC), Cork, Ireland
essajh@campus.ie

Abstract. It is commonly agreed that a 15-40% reduction of building energy consumption is achievable by efficiently operated buildings when compared with typical practice. Existing research has identified that the level of information available to Building Managers with existing Building Management Systems and Environmental Monitoring Systems (BMS/EMS) is insufficient to perform the required performance based building assessment. The majority of today's buildings are insufficiently sensored to obtain an unambiguous understanding of performance. The cost of installing additional sensors and meters is extremely high, primarily due to the estimated cost of wiring and the needed labor. From this perspectives wireless sensors technology proves to have a greater cost-efficiency while maintaining high levels of functionality and reliability. In this paper, a wireless sensor network mote hardware design and implementation are introduced for building deployment application. The core of the mote design is based on the 8 bit AVR microcontroller, Atmega1281 and 2.4 GHz wireless communication chip, CC2420. The sensors were selected carefully to meet both the building monitoring and design requirements. Beside the sensing capability, actuation and interfacing to external meters/sensors are provided to perform different management control and data recording tasks. The experiments show that the developed mote works effectively in giving stable data acquisition and owns good communication and power performance.

Keywords: Building automation systems, Wireless Sensor Network, Sensors interfacing and Motes deployment.

1 Introduction

A deeper understanding of system operation is possible if more detailed information is made available to Building Managers. This information must recognize the education and background of Building Managers if they are to fulfill their role with respect to organizational objectives and legislative compliance. Efficiency cannot be determined from displayed sensor readings without data access, storage and post processing. Scheduling information must be displayed concurrently with BMS data. All information used is dependent on accurate, robust and structured data.

S. Gabrielli, D. Elias, and K. Kahol (Eds.): AMBI-SYS 2011, LNICST 70, pp. 20–27, 2011.

Traditionally building automation systems are realized through wired communications. However, the wired automation systems require expensive communication cables to be installed and regularly maintained and thus they are not widely implemented in industrial plants because of their high cost [1, 2].

In recent years, wireless technologies have become very popular in both home and commercial networking applications. The use of wireless technologies offers distinctive advantages in the field of home and building automation as well [3-5]. First, installation costs are significantly reduced since no cabling is necessary. Neither conduits nor cable trays are required. Wireless technology also allows placing sensors where cabling is not appropriate for aesthetic, conservatory or safety reasons [4, 5]. With current wireless technology, a great challenge arises because of the level of expertise needed to fully make use of the sensors. The most sophisticated hardware often requires advanced knowledge of embedded programming to achieve the level of performance desired. A second issue is about the need for high active lifetime of the wireless installation which means the need for low power design starts with the obligatory use of energy efficient hardware (e.g., low supply voltages and support for sleep modes in microcontrollers) [6].

This paper is focusing on the development of a miniaturized Wireless Sensor platform that intended to be used for building sensing, meters interfacing and actuation. Next the deployment of large scale (around 60 nodes) of this platform was described in terms of network structure, topology and data presentation. The Environmental Research Institute (ERI) building, located at University College Cork (UCC), Ireland was designed as a green flagship building and a low energy research facility [7]. This building was chosen as the test bench for our large scale deployment because it is the most densely measured building on the UCC campus.

2 WSN Node Design

The mote is designed in modular mode. As Fig.1.a shows, the overview system contains four main units, these are data processing unit, RF communication unit, sensors/meters and actuation unit and power supply management unit. The data processing unit can make valid control for other units. To have deeper look into the developed system, the block diagram of the mote functional units is shown in Fig.1.b.

The multi-sensor layer was designed to interface with number of selected sensors as well as incorporating additional capability for use within the Building environment. This includes dual actuation capabilities for any AC/DC system using an external high power relay based system for devices which consume up to 280 V and 25 A (to turn on and off appliances) as well as an onboard low power switch to enable the actuation facility. The type of on-board sensor is either digital communicating with the microcontroller through serial bus interface like I2C or analogue connected with any of the ADC channels.

The two external sensors/meters interfaces are dedicated to any meter using MODBUS protocol [8] and variable resistance temperature sensors. The MODBUS meter is exchanging data/commands through RS485 serial communications. This interface layer was also designed to incorporate external flash memory (Atmel

AT45DB041). The layer features a 4-Mbit serial flash for storing data, measurements, and remote re-programming. The photos of both the RF and sensor layers are shown in Fig.2. The complete 3 layers stackable 25mm mote is shown as well.

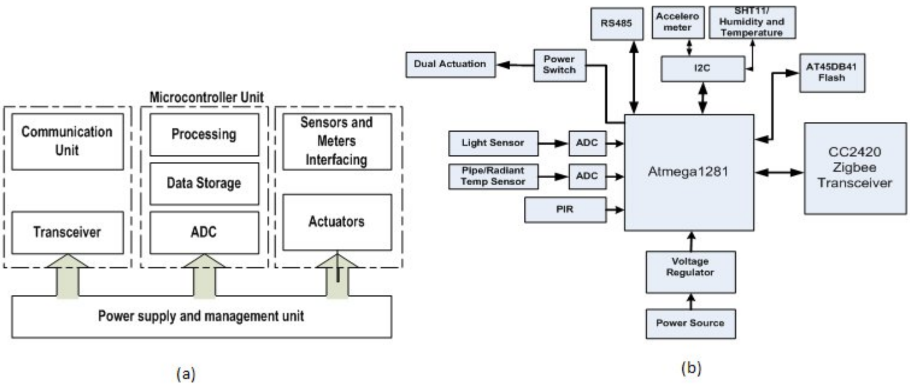

Fig. 1. (a) Top level system block diagram of the WSN mote (b) block diagram of the mote functional units

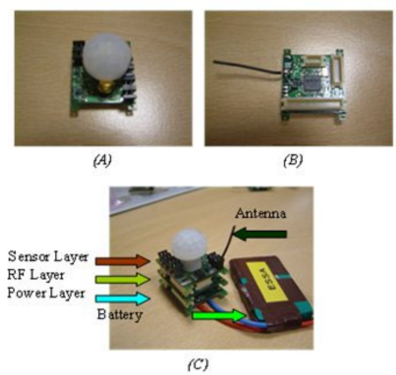

Fig. 2. Photos of the (a) Sensor layer, (b) Zigbee and processor layer, and (c) 25mm^2 mote

2.1 Sensors Selection

2.1.1 Occupation Sensor (Passive Infrared PIR)

Detecting the occupancy of the rooms inside the building was one of the essential requirements to be monitored, there was need to find suitable PIR sensor module. The Panasonic AMN44122 [9] was selected for this purpose since it provides the required functionality in a module that is smaller, more convenient and of lower energy consumption than the custom circuitry used in the prototype. Furthermore, the module provides a digital detection output that is used to trigger an interrupt on the processor when activity registers on the sensor. According to the datasheet of the PIR sensor, it has detection distance of maximum 10m (32.808ft) and detection range of 110° in horizontal and 93° in vertical.

A simple lab test has been performed to identify actual performance of the PIR sensor and obtained similar results to those in the datasheet as in Table 1. However, it was found that the actual detection region with high reliability is a little smaller than the detection region specified in the datasheet.

Table 1. The comparison of the AMN44122 PIR sensor with reference to date sheet

Items		Data Sheet	Lab test
Detection distance		10m (32.808ft)	9m (29.528ft)
Detection Range	Horizontal	110°	90°
	Vertical	93°	90°

2.1.2 Windows/Doors Status Monitoring

The detection of the windows/doors status was one of the building parameters required to be monitored by the WSN node. 3-axis accelerometer was selected for this application since it can provide useful angle information which helps to know how wide door/window is opened or closed. The LIS302DL is an ultra-compact low-power three axes linear accelerometer was integrated in the node design [10].

The main design challenge with using the accelerometer is that the microcontroller has to be continuously active to record sensor data which means high current consumption and short batter life time. In order to overcome this problem, a mechanical vibration sensor with very small package was used in this design to provide an external interrupt to the Atmel microcontroller when there is any kind of motion at any direction as presented by Fig.3.

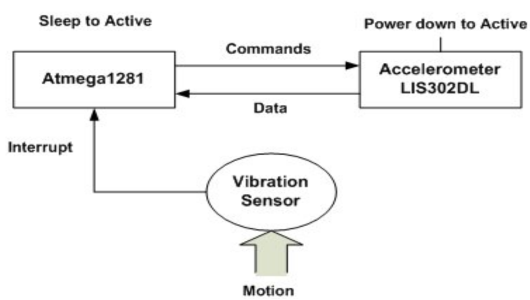

Fig. 3. Functional lock diagram of the motion sensor design

2.1.3 Water Flow /Electricity Meter Interfacing Using Modbus Handshaking

It is required to get the flow rate measurements from different locations inside the building where pipes made from different materials and have wide scale diameter size. The ultrasonic non-introductive was found to be the optimal solution for measuring the water flow rate of the water on building pipes since it is not disturbing the existing pipes installation and gives flexible testing option. Half duplex RS485/RS232 IC was used to interface the water flow meter with the Universal Asynchronous Receiver Transmitter (UART) of microcontroller using the standard industrial MODBUS protocol [8]. The STUF-300EB flow meter from Shenitech [11] was used for this application. It provides excellent capabilities for accurate liquid flow measurement from outside of a pipe.

2.1.4 Water Pipe/Radiant Temperature Sensor Interfacing

The monitoring of the water temperature that is passing in the building pipes was needed as part of the wireless sensor system. Surface Mount Temperature Sensor from SIEMENS [12] was selected for this application as non-introductive units and can be mounted directly on a pipe inlet to sense the temperature of water passing through. The sensor performance was compared with the existing wired sensors read by the Building Management System (BMS) as shown in Table 2.

Table 2. Verifying the readings of the sensor with the existence BMS

Temp ºC (BMS)	Temp ºC (Sensor)	Temp ºC (Calibrated Sensor)
20.25	19.01	20.01
23.12	21.03	22.03
30.45	29.5	30.5
45.21	43.2	44.2
48.87	47.62	48.62

3 Adopted Wireless Sensor Network (WSN)

3.1 WSN System Architecture

The adopted WSN architecture is based on recently released IETF IPv6 over Low power WPAN (6LoWPAN) (RFC 4944) open standard for IP communication over low-power radio devices – IEEE 802.15.4 represents one such link. WSN LoWPAN networks are connected to other IP networks through one or more border routers forwarding packets between different media including Ethernet, Wi-Fi or GPRS as shown in as shown in Fig.5 [7].

3.2 ERI Data Storage and Representation

To provide sensed data to the end user (or other software components) for the purpose of building performance monitoring (BPM), there are a number of conceptual and practical challenges that need to be overcome. The conceptual challenges can be the definition of BPM to different stakeholders of a building [13].Practical challenges include data quality, availability and consistency, and benchmarking. A Data Warehouse (DW) implementation was created to store large data sets of data provided

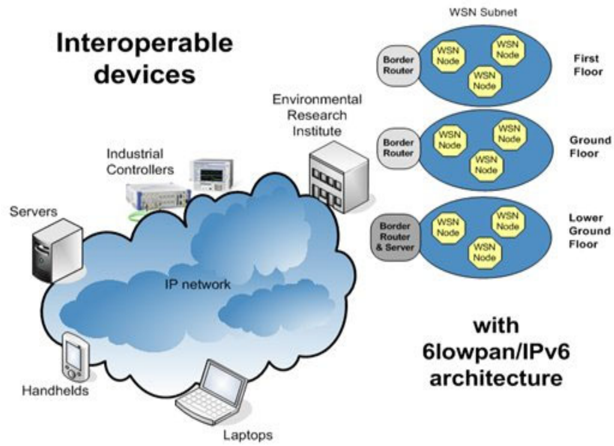

Fig. 5. WSN in the broader view

by the data streams of the WSN in ERI [14]. In Fig.6, the staging area was designed to support data from multiple sensor, meter and actuator types. This data is processed to form data cubes that support the presentation of relevant building performance measures to stakeholders.

To extract the environment information from the WSN deployment in the ERI, a Service Orientated Architecture (SOA) was used [15]. For the ERI deployment, data is gathered from the first and ground floor and sent through the wireless backbone to the embedded PC (gateway) in the basement of the building. From embedded PC, a SOA connection is maintained to a data warehouse (DW). Fig.6 shows the architecture used to gather data from the sensors and present data through a graphical user interface (GUI) to the end user.

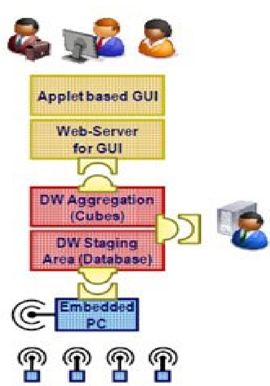

Fig. 6. SOA for WSN to DW and DW to GUI

Sample of the obtained results using a building operator GUI are displayed in Fig.7 showing one day data from light (immunology), radiant (immunology), door (seminar room) and occupancy (seminar room). Fig.8 shows samples of the selected deployment sites. In total (60) nodes were deployed in the selected three main zones within the ERI building to perform various functions of sensing and monitoring. This building performance data will be used to support decision making for facility manager and building operators to optimize maintenance activities [15] and assist in fault detection and diagnosis.

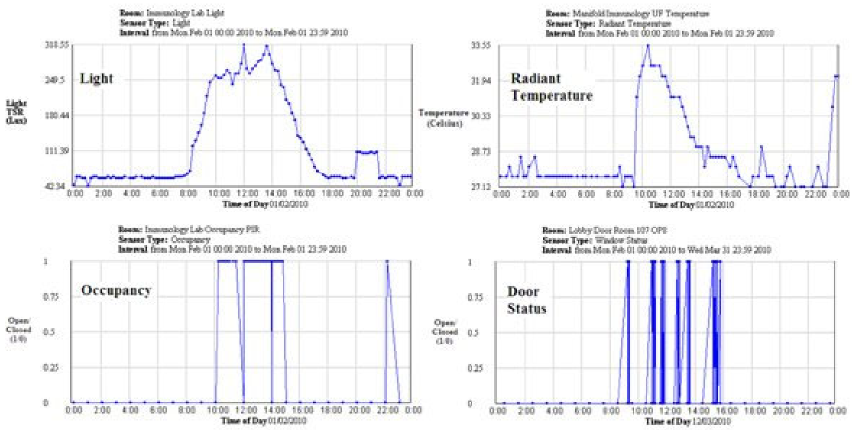

Fig. 7. GUI one day recorded data of (a) light, (b) radiant temperature, (C) occupancy and (D) Door status

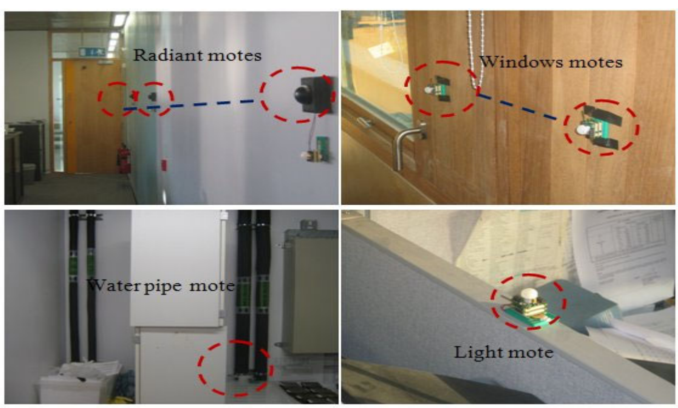

Fig. 8. Number of Deployment Sites for (Window, Radiant, Light and Water pipe)

4 Conclusions

This paper presents the design and development of a miniaturized WSN mote based on Zigbee technology for building monitoring, exploring its system control management and technology characters. The stackable technique was adopted in this work to manufacture efficiently the mote layers within small cubic size. The node can implement wide scale of stable sensors/meters data acquisition to provide the needed functions. An efficient BPM was developed to maintain the data streams from all wireless sensors to the data warehouse and at the same time provide the end user with useful information. The experiments in this paper demonstrate the capabilities and reliability of the proposed mote platform and adopted WSN topology to perform the desired tasks and extend the current BMS sensing parameters.

References

1. Gutiérrez, J.A.: Int. J. Wireless Information Networks 14, 295–301 (2007)
2. Österlind, F., Pramsten, E., Roberthson, D., Eriksson, J., Finne, N., Voigt, T.: In: Proc. IEEE Sym. On Emerging Technologies and Factory Automation, pp. 1376–1379 (2007)
3. Keller, M., O'Donnell, J., Keane, M., Menzel, K., Barton, J., Ó'Mathúna, C., Klepal, K., Pesch, D.: Buildwise: Building a Sustainable Future, Wireless Sensor Networks for Energy and Environment Management in Buildings, D1 Specification Report University College Cork (2007)
4. Jang, W.S., Healy, W.M., Skibniewski, M.J.: J. Automation in Construction 17, 729–736 (2008)
5. Reinisch, C., Kastner, W., Neugschwandtner, G., Granzer, W.: Proc. IEEE Int. Conf. on Industrial Informatics, INDIN (2007)
6. Xu, J., You, B., Cui, J., Ma, J., Li, X.: Proc. SPIE – 5th Int. Sym. on Instrumentation Science and Technology, p. 7133 (2009)
7. Spinar, R., et al.: Management with IP-based Wireless Sensor Network. In: European Wireless Sensor Networks, EWSN 2009 (2009)
8. MODBUS Industrial Protocol, `http://www.modbus.org`
9. AMN44122 Passive Infrared (PIR) Motion Sensor, Passive, `http://pewa.panasonic.com/`
10. LIS302DL, 3-axis smart digital output accelerometer, `http://www.st.com`
11. STUF-300EB Ultrasonic Water Flowmeter, from Shenitech, `http://www.shenitech.com`
12. Surface mount pipes temperature sensor, `http://www.buildingtechnologies.siemens.com`
13. Wang, Y., Stack, P., Tumwesigye, E., Menzel, K.: Aspects of Interface Design for Energy Management in Buildings. In: von Both, P., Koch, V. (eds.) Proc. Forum Bauinformatik, pp. 359–370. University Karlsruhe, Karlsruhe (2009); ISBN 978-3-86644-396-9
14. Ahmed, A., Menzel, K., Ploennigs, J., Cahill, B.: Aspects of Multi-dimensional Building Performance Data Management. In: Wofganghuhnt (ed.) Proc.Computing in Civil Engineering EG-ICE Conf. Computation in Civil Engineering, TU Berlin, Germany, pp. 9–16 (2009); ISBN 978-3-8322-8287-5
15. Stack, P., Manzoor, F., Cahill, B., Menzel, K.: A Service Oriented Architecture (SOA) for Building Performance Monitoring. In: Gürlebeck, K., Könke, C. (eds.) Int. Conf. on Applications of Computer Science and Mathematics in Architecture and Civil Engineering (2009)