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Wireless Sensor Network For Indoor Air Quality Monitoring

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A home-made and home-developed sensor network was proposed and developed in this paper for indoor air quality monitoring. The network consists of a base station connected to internet and several autonomous nodes equipped with different sensors to measure temperature, humidity, light and air quality. A specific program made with Labview is created to configure and supervise the operation and the measurements of the network. The communication between nodes and host is based on the standard IEEE 802.15.4 (Zig-Bee protocol) using the XBee module of Maxstream and the communication between host and PC is performed through an USB interface.

1. Introduction

In the near future, Ambient intelligence (AmI) will be in most houses in different ways. Wireless sensor networks (WSNs) are commonly recognized as one of the technological cornerstones of AmI [Culler, 2004]. Sensor Networks are agile, low-cost, low power and can collect a huge amount of information from the environment in order to actuate and control different facilities. Using a biological analogy, a sensor network can be seen as the sensory system of the intelligent environment "organism". Sensor networks are irregular aggregations of communicating sensor-nodes, which collect and process information coming from on-board sensors, and they exchange part of this information with neighbouring nodes or with nearby collection stations.

Sensor networks promise to revolutionize sensing in a wide range of application domains because of their reliability, accuracy, flexibility, costeffectiveness and ease of deployment. Several applications have been described for WSNs using gas sensors, despite of the youth of these devices, mainly outdoor applications, i.e. Fire detection (Brini, 2011), chemical processes and environment (Bonastre, 2012) and indoor applications like room environment monitoring (Chung, 2006) or air quality monitoring (Yu, 2011).

Recently, with increasing living standards and expectations for comfortableness, the use of residential air conditioning is becoming widespread. The control and monitoring of indoor atmosphere conditions represents an important task with the aim of ensuring suitable working and living spaces to people. However, the comprehensive air quality monitoring which include monitoring of temperature, humidity, air quality, etc., is not so easy to be monitored and controlled.
This work shows a simple approach of a sensor network to monitor several parameters interesting for the indoor environment control, like temperature, humidity, light and air quality.

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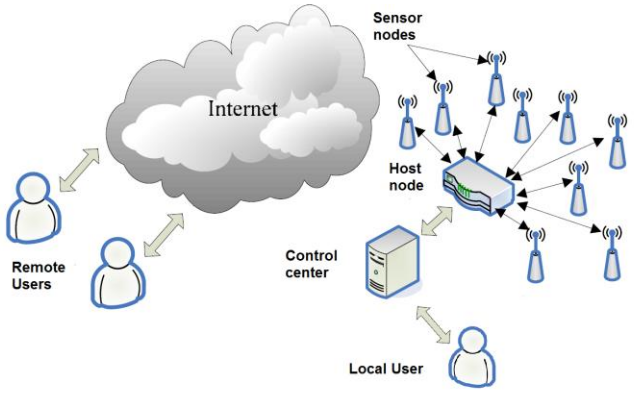

Figure 1: Wireless Sensor Network architecture.

1.1 Fundamentals of Wireless Sensor Networks (WSNs)

Basically, WSNs are formed (Figure 1) by a great number of small devices – the so-called sensor nodes or motes – that are able to obtain information from their surroundings by means of transducers and transmit it towards a sink node using wireless communications [10]. This information, after the suitable data handling, is stored by the sink node on a database, where (usually through the Internet) it is available for use, be it in real time or for statistical analysis. WSNs comprise three different subsystems, namely: sensor nodes; sink node; and, information management system:

Sensor nodes. Sensor nodes are systems of low cost, small size, and low consumption, capable of getting information from the environment, processing it, and sending it to the Information Management System (IMS). They comprise the following elements:

(1) Microcontroller system (computer of low cost, low consumption, and small chip) that is the core of the node. Unfortunately, these characteristics imply certain limitations, especially for memory and computing power.

(2) Power supply unit. Although there are nodes that can be connected to the main power supply, WSNs usually require autonomous functioning, so this system often comprises batteries or even energy- harvesting systems. Unlike most computer systems (where power supply is a secondary aspect), WSNs heavily depend on this aspect.

(3) WSN, whose range is usually short, due to the energy restrictions mentioned above.

(4) Transducers, which allow the node to obtain data from the surroundings for later processing and transmission. These devices are the cornerstone of the different types of sensor node. Obviously, they should be compatible with WSN features.

(5) Occasionally (not shown in Figure 1), the system is completed with actuators, which can act on the surroundings, then giving rise to the so-called WSANs (Wireless Sensor and Actuator Networks).

The host node or coordinator. It is a special node, usually a high-power microcontroller system or even a computer or a laptop, which carries out different functions within the system. On the one hand, it is the target of the information obtained by all the sensors. On the other, it is in charge of organizing and managing the whole network. Finally, it is also involved in data evaluation, be it for detection of alarm situations (the corresponding warnings being generated) or performing fault-tolerance actions (e.g., to discard erroneous measurements, or even to ask for their repetition). Basically, it is formed by the following elements:

(1) Wireless internal communication system, compatible with the one utilized by the sensor nodes.

(2) Computing system, based on a high-power microcontroller or a computer.

(3) Power-supply system.

(4) Outer communication system, by means of which the sink node is able to provide the users with the information retrieved by the sensor nodes

(5) Optionally, the sink node may store the information.

The information management system (IMS). It is configured around a database, on which all the information obtained by the different sensor nodes is stored. Moreover, important details other than the value itself (origin and time) are also indicated. This database is handled using software that enters the data from the sink node and offers them to users (normally through the Internet). It may be located in the sink node or in any other remote computer (including hosting systems). We point out that the information can be offered in a friendly (and universal) way using browsers.
The most usual architecture of WSNs is shown in Figure 1. As we can see, the sensor nodes collect the information – by means of the appropriate transducers – periodically or when an event occurs (e.g., value change, threshold exceeded, or alarm activation). After suitable data handling, this information is transmitted using a WSN. However, the absence of wires makes the nodes depend on their own energy resources, so multi-hop mechanisms are adopted to reduce energy consumption. In this sense, other techniques (e.g., data fusion or aggregation) may also be utilized [12]. ZigBee, Bluetooth and Wi-fi are the outstanding standards employed in these WSNs.
We can see that the information gathered by the host node is stored on a database, be it local or remote, accessible through other communication systems (e.g., Internet), regardless of the physical channel (e.g., Ethernet, WiFi, or 3G technology).

1.2 ZigBee Protocol

The ZigBee or IEEE 802.15.4 protocol has the following general characteristics:

- Dual PHY (2.4GHz and 868/915 MHz)
- Data rates of 250 kbps (@2.4 GHz), 40 kbps (@ 915 MHz), and 20 kbps (@868 MHz)
- Optimized for low duty-cycle applications (<0.1%)
- CSMA-CA channel access: Yields high throughput and low latency for low duty cycle devices like sensors and controls
- Low power (battery life multi-month to years)
- Multiple topologies: star, peer-to-peer, mesh
- Addressing space of up to:
    - 18.45E+18 devices (64 bit IEEE address)
    - 65,535 networks
- Optional guaranteed time slot for applications requiring low latency
- Fully hand-shaked protocol for transfer reliability
- Range: 50m typical (5-500m based on environment)

The frame structures have been designed to keep the complexity to a minimum while at the same time making them sufficiently robust for transmission on a noisy channel. Each successive protocol layer adds to the structure with layer-specific headers and footers.
The IEEE 802.15.4 MAC defines four frame structures:

- A beacon frame, used by a coordinator to transmit beacons.
- A data frame, used for all transfers of data.
- An acknowledgment frame, used for confirming successful frame reception.
- A MAC command frame, used for handling all MAC peer entity control transfers.

The data frame is illustrated in Figure 2.

2. Material and methods

2.1 Network architecture

A block diagram of the network architecture is shown in Figure 1. An image of the sensor network developed in this work is shown in Figure 3. It basically consists of several sensor nodes that are connected through ZigBee to the host node or the coordinator of the network. It is connected to a PC with the control program through USB interface. The control computer stores the measurement data and allows the configuration and supervision of the whole network.

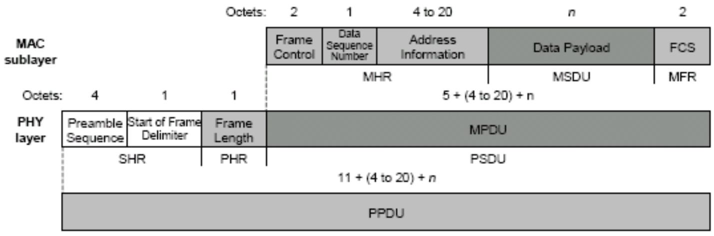

Figure 2: Data frame of IEEE 802..15.4/ZigBee Protocol.

The main parameters of the network are shown in Figure 4 and below:

- 16 bits addressing mode has been used because few nodes are used. In case of using large number of nodes, 64 bits addressing is recommended.
- The Address 0001, 0002, 0003, 0004 has been chosen for the nodes and AAAA for the coordinator.
- The channel used is 0xC and the ID of the Personal Area Network (PAN) was 0x3332.

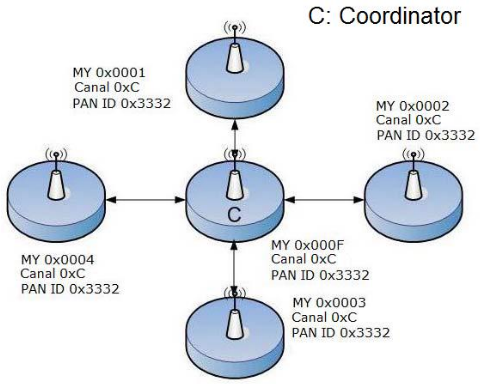

Figure 3: Image of the nodes and host of the network. *Figure 4: Configuration parameters*

2.2 Sensors Nodes

The sensors nodes (Figure 5) are composed by the following devices (see also in Figure 5):

- Communication and processors module: XBee and XBee pro modules from Maxstream are used in these modules.
- Conditioning Signal and Conversion Module: electronic circuits and instrumentation has been designed for adapting the sensor signals to the range of the conversion modules. Recommendation of sensor builders has been used to the design of the instrumentation.
- Sensor Module
    - Temperature sensor: LM35DZ from National Semiconductor has been used.
    - Humidity sensor: HIH–4000 from Honeywell with temperature compensation.
    - Light sensor: light dependant Resistance NSL-19M51 from SILONEX.
    - Quality air sensor: TGS 2600 from FIGARO with High sensitivity to gaseous air contaminants (hydrogen, ethanol, iso-butane and carbon monoxide).
- Power Supply Module: it is designed using commercial electronic devices.

2.3 Control Program

The control program is realized using Labview from National Instruments and is executed in the Control Computer. The main aims of this program are: to configure the nodes and the network and capture the measurements made by the sensors nodes through the host node using USB (between the PC and host) and ZigBee interface (between host and sensor nodes). The program has two important blocks: the front panel where the interaction between the user and the program is produced and the block diagram where the code of the virtual instruments is programed.

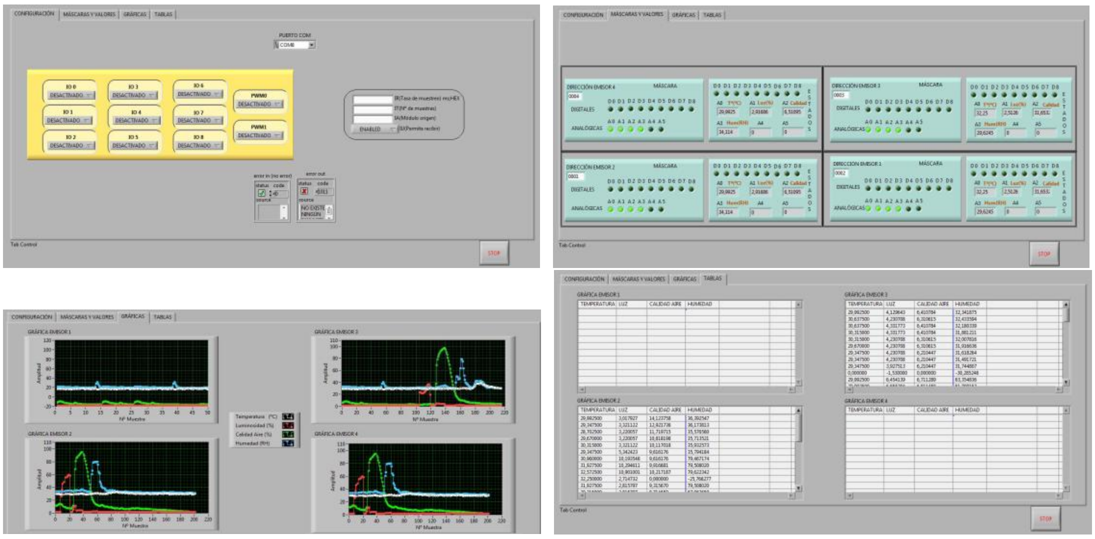

Figure 5: Front panel of the control program: a) Configuration, b) Masks and values, c)Graphs and d)Tables.

Front panel: The user panel is shown in Figure 5. It is composed by several tabs in order to offer the functions of the control program in an organized way:

- Configuration: The first tab (Figure 5a) corresponds to the configuration of network parameters and input / output module coordinator (options for I / S digital and analog outputs for PWM). You can also configure the inputs / outputs of the XBee coordinator as digital input, digital output, analog input,. In the right panel set the transmission functions such as sampling rate, the number of samples before shipment, the source module address (if given), and receiving permission. At the top you can select the serial port used to connect to your computer. Also shown are the error codes for debugging.
- Masks and values: the second tab (Figure 5b) displays the status of each I/O of the four modules. It can be seen the information received from each of the transmitters: the I/O mask that are being used in the corresponding XBee module, and if is applicable to a digital or analog signal. The digital or analog readings also are shown for each channel that is being used.
- Graphs: The third tab (Figure 5c) corresponds to a graph for each sensor node. Each chart shows four signals (one for each sensor). The white lines correspond to the temperature measurement in °C, the red are light measurements (%), the air quality in green (%) and, finally, the blue ones are measurements of humidity (RH).
- Tables: in the fourth tab (Figure 5d) there are four tables. In each one of them, data received from each of the sensors (temperature, light, air quality, and humidity) are shown. These data could be exported to different types of files.

Block Diagram: The main tasks performed and programmed were:

1. Establish the communication with the serial port.
2. Enter the system into the command mode.
3. Insert the values of programation of the transmission.
4. Configure the parameters of the coordinator inputs and outputs.
5. Reading the data received.
6. Extract the transmitter module address and compare it with the four used.
7. Show the mask data and states. The sensor data are adapted to be shown in degrees,% darkness,% ppm and RH.

3. Results

The results shown in this work correspond to the working test of the network and sensor nodes. In this way, it has been configured and several measurements are taken. As an example, measurements from the excitation of the sensors have been performed in order to check the operation of sensors, nodes communication and the whole system. The values of the sensors before the excitation were: Temp: 29.99ºC, Light: 1.70%, Air quality: 11.71 and Humidity: 34 %RH. Next, the sensors were checked one by one in order to detect an increase in the light (dark), air quality (100 ppm of ethanol), humidity (80%) and temperature (40ºC). These results can be observed in the graph showed in the control program (Figure 7).

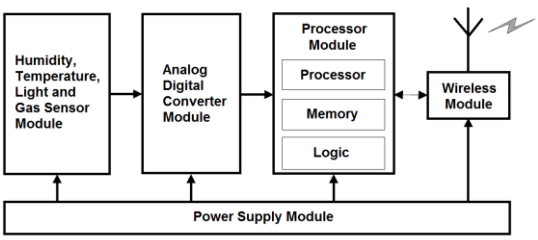

Figure 6: Block Diagram of the sensor nodes.

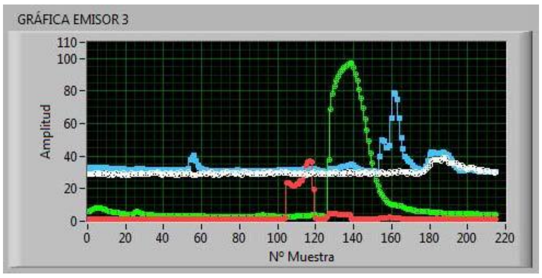

Figure 7: Measurements of one of the sensor nodes: Temperature (white), Light (Red), Air Quality (green) and Humidity (Cyan).

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