Wireless Sensor Network Application for Environmental Impact Analysis and Control

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***Abstract*- Traditional Wireless Sensor Networks (WSNs) applications take advantage of the new low cost low power consuming integrated sensors that appear with the evolution of Micro Electromechanical Systems (MEMS). This kind of sensors is suitable for WSNs, due to the reduced size, their interfaces and their low power consumption. However, during the last years, WSNs have found new niches of application where such sensors are not usable, due to the nature of the parameter to be measured. In these scenarios, new approaches must be taken in order to satisfy the requirements. But new problems appear, like cost and size increase. In this paper, an application where parameters like gas concentration, conductivity or pH have to be measured in a coffee factory is presented. The drawbacks of such a solution are highlighted, and the solution in the field of the wireless sensor networks adopted is detailed.**

I. INTRODUCTION

Wireless sensor networks represent one of the most outstanding technologies in the last years, and several research disciplines have appeared to cover the special needs of a this kind of systems, like hardware platforms, communication protocols, security issues or operating systems, among others.

A standard application scenario for WSNs is a set of nodes deployed in an environment, in an unattended way. The network is autonomous, and in principle, no human intervention is necessary for several months or even years. Thus, the energy consumption of the nodes is critical for the system performance.

Due to the special features of such a system, special care must be taken with the hardware design stage. Of course, the sensors and/or actuators chosen for a specific application have a deep impact in the performance of the nodes. In commercial platforms like TelosB [1] or Imote2 [2], among others, usual implementations of sensor boards incorporate cheap integrated sensors, suitable for non demanding applications. These sensors are small and fit within the requirements of the WSNs.

However, new applications have appeared during the last years, with new demands and requirements, and the kind of sensors mentioned before are not suitable. Other more consuming, bigger and more expensive sensors are necessary.

Moreover, traditionally, wireless sensor networks are battery powered, reason because it is critical the HW design to reduce power consumption. Anyway, sometimes such solution may not be the best, because the application drives the final implementation.

In this paper, all the topics described before join together and an application with non traditional WSN sensors and line powered is presented.

The target is to measure different parameters in an instant coffee factory, in order to detect potential impacts for the environment, and to control them.

The rest of the paper is organized as follows. In section II an overview of the HW platform used for the deployments is shown. In section III, the application is described and in section IV, the HW modifications and additions to the platform presented in section II are detailed. Finally, in section V some conclusions about the present work are established.

II. COOKIE SENSOR NODE

The WSN node used in this application is the Cookie node [1]. This node was designed with a main philosophy in mind: modularity.

The Cookie is composed of four main layers (more layers can be added in future versions): processing, communication, power supply and sensors. Every layer carries out a specific task, and these encapsulates the functionality. In the following paragraph these layers are detailed:

1. Processing: This is the heart of the node. It includes an 8052 uC from Analog Devices (ADuC841) and a Xilinx XC3S200 Spartan 3 FPGA. The uC and the FPGA share three 8-bit ports for communication. Hardware modifications had to be carried out to connect the JTAG port of the FPGA to the uC, to make possible remote reconfiguration. A second version of this layer with a MSP430FG439 microcontroller from Texas Instruments and an AGL250 FPGA from Actel is available.

2. Communication: The last version of this layer includes a ZigBee module (ETRX2 from Telegesis). This module is controlled by the uC through the UART port. A layer version with Bluetooth is also available.

3. Power supply: This layer generates all the voltages needed within the Cookie. Two versions have been developed, the latest with USB included, which allows power supply from a PC and serial programming for the uC.

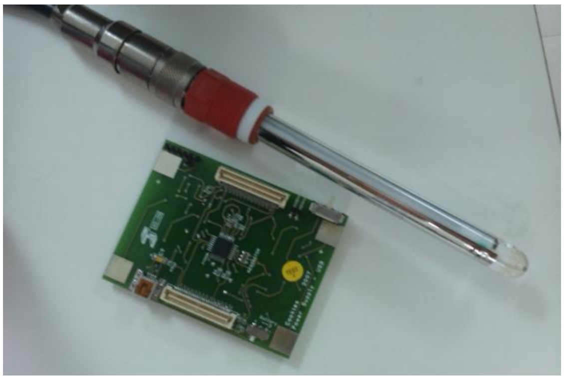

Fig. 1 pH sensor and power supply layer for Cookie platform

4. Sensors: This layer includes those elements which are intended to take measures from the environment. Up to now, three different layers have been developed for the Cookie. These layers include sensors of acceleration, temperature and humidity, light, infrared and deformation.

The sensing layer includes small low power and low cost sensors. For the application presented in this paper a new version had to be developed.

With this implementation strategy, the adaptation to the new scenario implied the redesign of the sensor layer, with the conditioning circuit needed for the new sensors, so the rest of the platform remains except the power supply and the sensor layer.

III. APPLICATION

A wide range of wireless sensor network applications related to food industry have already been developed. In the majority of them, the sensors are small, cheap and easy to use. The main difficulties of the application are the data flow requirements and the use of chemical sensors.

Applications for quality control in monitoring of fruit transport [3] or the use of wireless sensor networks to obtain information about the amount of food and water consumed by animals in farms [5], normally, use sensors to measure light, vibration, pressure or human and animal presence. These measurements are quite easy to manage but, sometimes, the parameters are not so simple.

In this paper, an application to analyze environmental aspects in a coffee factory is detailed. The main issue of the deployment is to obtain data from waste water and gas emissions in the factory, to evaluate the environmental impact. The data will be sent to a software platform in order to make the impact analysis. The main advantage of the WSN deployment will be the possibility of getting data from the processes and emissions during run time. This capability is very important when trying to comply with regulations or detecting problems in coffee manufacturing, which will improve the quality standards of the factory.

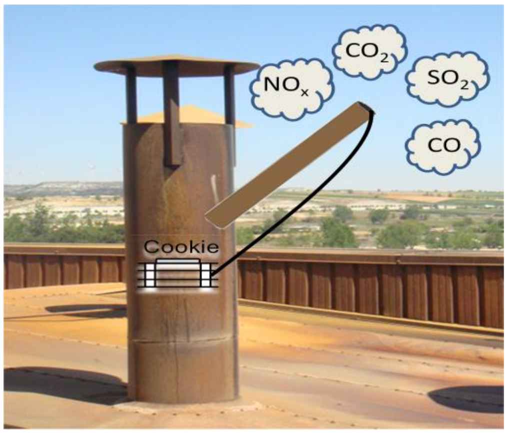

Fig. 2 Node placement for gas emissions

The parameters to be measured in the factory will be: pH, conductivity, temperature of the water, and gas emissions of CO_2, SO_2, CO, NO_x. In case of the air quality measurements, the sensors are small, simple and cheap, as usual in the field of WSNs. However, the sensors to analyze the quality of waste water are very expensive and too big to fit in the wireless platform, as seen in Figure 1.

The processes involved in the instant coffee manufacturing are: toasting, blending, agglomeration, grinding, drying, etc. The emissions of CO_2, SO_2, CO and NO_x, in those activities, especially during toasting, are quite important, so it is necessary to keep a tight control to avoid accidents and to comply with regulation. In order to measure the gas emissions in factory chimneys, the nodes will be installed as shown in "Fig. 2". Due to temperature conditions of the gases, it is not possible to put the sensors directly inside the tube of the chimney, so an additional tube has to be installed to divide and cool the gas flux.

The measurements in the factory have been taken, approximately, twice a year by an accredited laboratory. From the point of view of the regulation issues, it may be enough, but when trying to reduce the environmental impact it is completely inadequate. With the aim of reducing this impact and the cost of the process analysis, we have designed a new method to measure these parameters in a cheap, disregarded and non intrusive way.

There are two main points to place the nodes, one of them

Fig. 3 Sewage treatment plant

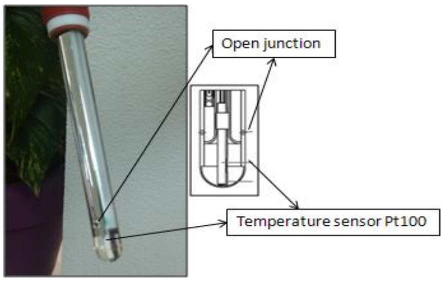

Fig. 4 Processing layer (uC on the left, FPGA on the right) and full Cookie platform

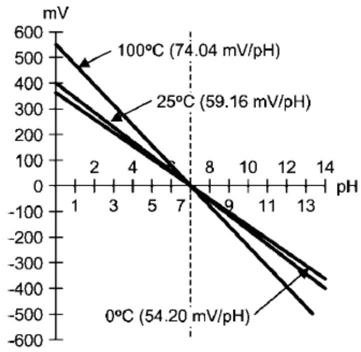

Fig. 5 Output voltage-pH, temperature dependant

to measure the air parameters, and the other one to measure the water quality aspects. The nodes to measure the gas concentration will be at the toaster and dryer chimneys as shown in "Fig. 2". The water parameters will be taken at the sewage treatment plant output, in order to analyze the conductivity, pH and temperature values of waste water. This place is shown in "Fig. 3".

It is important to highlight that, although the sensors for the water measurements are very expensive (more than 600€ in the case of pH), in the long run it is worth the investment because the platform will provide information continuously instead of monthly, as it has been done until now.

Once the deployment is done, and the data is sent to the software platform, the software itself can develop an impact analysis and, at the same time, provide information about the efficiency of the manufacturing processes.

IV. HARDWARE DESIGN

A. Sensors

Due to the necessity of covering two different zones like air and water, the target of the deployment must be divided in two parts.

A.1) Water measurements

To analyze the water quality, pH, conductivity and temperature will be measured.

PH sensors work calculating the voltage difference between two electrodes [3]. One of them has to be immersed in a solution with referenced pH value and the other, in contact with the sample solution through a glass bulb. Therefore, the output signal is the voltage difference between them. Due to the high impedance of the glass bulb, it is necessary to use an amplifier with the smallest input bias current as possible; because even a small input current can produce a big error in the output voltage (the LMP7721 with 3pA of input bias current is being used [4]). Another difficulty when doing the pH measurement is the temperature compensation; as is shown in the "Figure 4", the output voltage depends on the temperature of the sample solution.

The temperature compensation will not be implemented in hardware because it will be easier to do it through the µC. Besides, the temperature measurement will be done both with the pH and the conductivity sensor, so it is necessary to calculate the average value between them before doing the compensation. The pH sensor can be seen in the "Figure 5". It is important to notice that, both the measurement electrode and the temperature sensor are inside the glass bulb.

The conditioning circuit to adapt the voltage signal of the pH electrode, consist mainly, of a precision operational amplifier and an amplifier stage to put the signal values in the range of 0-2.5V (0V for pH=0 and 2.5V for pH=14). It is important to highlight, that the Cookie's power supply board does not give negative voltage, so it will be necessary to put a charge pump to invert the supply voltage.

Conductivity shows the amount of ionic compounds dissolved in waste water. Conductivity is measured as the inverse of resistance between two terminals [8]. Both the area of these terminals and the distance between them are essential to calculate the conductivity value. The expression to calculate this value is Conductivity=1/R*k, where R is the resistance between both terminals, and k is the cell constant k=d/A, with d the distance between terminals and A the area of each terminal. Therefore, our aim will be to obtain the R value, while the k value will be given by the manufacturer. As seen in the previous expression, the equation is not linear, so it will be necessary to adapt it also by software. The conditioning circuit must have a first stage to obtain an output voltage directly dependent on the R value. The second stage will consist of a rectifier, made of one operational amplifier and two diodes to assure the correct values inside the measurement range. In this second part, it will be possible to add some resistors to obtain the desired gain to adapt voltage levels. Once we have an output value between 0 - 2.5V dependent on the R value, the transformation to get the correct value of the conductivity will be done through the µC.

The temperature will be measured using a Pt100 resistor in the case of pH, and a Pt1000 in the case of conductivity. Both sensors have a 3-wire connection, [6].

In the table below some values of this parameters are shown:

TABLE I
WATER PARAMETERS

Parameters	Date	Value	Error range	Units	Limit value
Conductivity (25ºC)	24-10-08	1297	±71	µS/cm	-----
pH	24-10-08	7.53	±0.35	pH units	6-10

A.2) Air measurements

As seen above, the emissions to be measured are: CO_2, SO_2, CO, NO_x. The toxic gas sensors are electrochemical cells that operate generating a current linearly proportional to the fractional volume of the toxic gas [9].

In “Table 2” some values of the factory emissions are shown.

TABLE II
EMISSION VALUES

Parameter	Values			Units	Limit Value
CO	<48	<48	<48	ppm	500
SO2	<140	<140	<140	mg/m3N	4300
NOx (NO2)	<100	<100	<100	ppm	300

The conditioning circuit used is the one recommended by the manufacturer: the idea when designing the gas PCB is to have only one conditioning circuit, so that when changing some parameters, the measured gas could be changed as well. In this way, it would be possible to test the correct behavior of the platform using only one sensor layer.

Some of these gases are toxic. Because of that, having instant values inside the workplace is very important. Due to this necessity, among others, the power consumption of the node became higher than in normal applications. To solve this problem an adaptation of the power supply board of the platform has been done.

B. Power Supply Board

Due to the reasons explained above, an adaptation of the power supply board is necessary. Because of the high data flow and the conditioning circuits, the consumption of the platform became bigger than usual. After discussing the problem with the factory manager, the verdict was that it would be cheaper for the factory to put sockets where the nodes are going to be placed. So that, a line powered Cookie has been designed.

As seen before, one of the main features of the Cookies platform is the modularity so, the line powered Cookie is a new contribution for it. With this new design the Cookie can be fed in four different ways depending on the position of a manual switch:

- External Source
- USB connection
- Lithium battery
- Electrical network

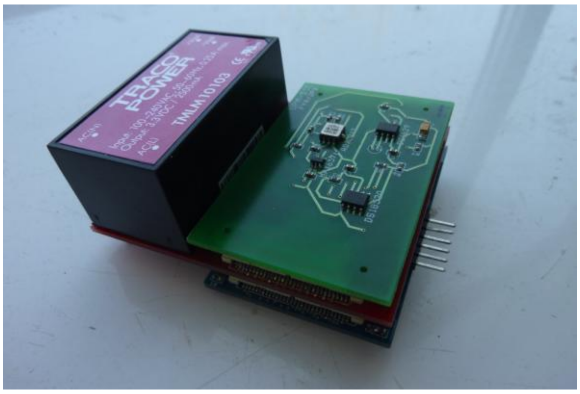

Fig. 6 Platform used in the application, with the new design of the power supply board

For this application the most important is the one from the electrical network.

Depending on the sensor necessities, we can convert the voltage from the socket, into 5V or 3.3V (TRACO POWER 10103 for 3.3V and 10105 for 5V). All the conditioning circuits need 3.3V, but sometimes there could be some sensors with higher supply voltage.

The PCB design allows us to choose whether we need the 3.3V regulator or not, because the TRACO already gives this value. In addition to these values, there are also two more regulators which provide 1.2V and 2.5V.

There are, of course, advantages and drawbacks. Although with this design the use of cables is necessary, it is the cheapest and easiest solution for this application, and shows the modularity of the platform. Besides, the size of the PCB is bigger than a normal Cookie layer, but smaller than the previous version which included AA batteries.

In “Fig. 6” can be seen the line powered PCB and the size compared with the TRACO POWER.

V. CONCLUSIONS

In this paper, a new application of WSNs is presented. The advantages of using environmental control unattended systems are many: real-time control of emissions and pollutants (air, water) and easy tracking of emissions data for complying with existing regulations (i.e. ISO 14000), among others. The application presented here may be an example of something that could be installed in different types of food industries, as it is part of a whole system, including a software tool for managing environmental issues. Another important feature of this application is the availability of power lines in the factory, which makes possible the use of “power-hungry” sensors, which are really needed for measuring most of the variables. In order to comply with the requirements, several sub-systems have been needed, that are integrated in the *Cookies* architecture, demonstrating that its layered modular configuration is well suited for applications like this, which require small number of pieces and well calibrated transducers and electronics.

In the following months, the first "in-field" results will be available, as the plan is to make an installation of the system in an instant coffee factory.

VI. ACKNOWLEDMENTS

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REFERENCES

[1] J. Polastre, S. Szewczyk, D. Culler, "Telos: Enabling Ultra-Low Power Wireless Research", *in Proceedings of the 4th IEEE/ACM International Conference on Information Processing in Sensor Networks (IPSN'05)*, pp. 364 - 369, Los Angeles, California, USA, April 2005.

[2] R. Adler, M. Flanigan, J. Huang, R. King, N. Kishalnagar, L. Nachman, C. Wan, M. Yarvis, "Intel mote2, An Advanced Platform for Demanding Sensor Network Applications", *in Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems (SenSys'05)*, pp. 298 – 298, San Diego, California, USA, November 2005.

[3] J. Portilla, A. de Castro, E. de la Torre, T. Riesgo, "A Modular Architecture for Nodes in Wireless Sensor Networks", *Journal of Universal Computer Science (JUCS)*, vol. 12, nº 3, pp. 328 - 339, March 2006

[4] L. Ruiz-Garcia, P. Barreiro, Rodríguez-Bermejo, I. J. Robla, "Monitoring intermodal refrigerated fruit transport using sensor networks", *in Spanish Journal of Agricultural Research*, pp. 142-156, 2007

[5] P. Sikka, P. Corke, P. Valencia, C. Crossman, D- Swain, G. Bishp-Hurley, "Wireless Adhoc Sensor and Actuator Networks on the farm", *in Proceedings of the 5th International Symposium on Information Processing in Sensor Networks (IPSN'06),* pp. 492 – 499, Nashville, Tennessee, USA, April 2006.

[6] Designing With pH Electrodes. National Semiconductor Application Note 1852 Jason Seitz September 25, 2008

[7] http://www.national.com/ds/LM/LMP7721.pdf

[8] http://www.mbhes.com/conductivity_measurement.htm

[9] Miguel A.Perez García, Juan C. Alvarez Antón, Juan C. Campo Rodriguez, Fco.Javier Ferrrero Martín, Gustavo J. Grillo Ortega, "Instrumentación Electrónica" Edit. Thomson.

[10] http://www.alphasense.com/pdf/AAN_104.pdf