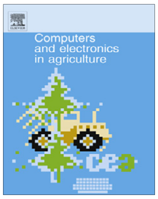
Computers and Electronics in Agriculture 103 (2014) 11–16

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag



Assessing the dynamic behavior of WSN motes and RFID semi-passive tags for temperature monitoring

Ricardo Badia-Melis [a,*], Javier Garcia-Hierro [b], Luis Ruiz-Garcia [c], Tatiana Jiménez-Ariza [d], José Ignacio Robla Villalba [b], Pilar Barreiro [d]

[a] *Department of Electrical Engineering, College of Engineering, ENB118, University of South Florida, 4202 E. Flower Ave., Tampa, FL 33620, USA*

[b] *Sensors Technology Laboratory, Centro Nacional de Investigaciones Metalúrgicas, Consejo Superior de Investigaciones Científicas (CENIM-CSIC), Avenida Gregorio del Amo, 8, 28040 Madrid, Spain*

[c] *Departamento de Ingeniería Rural, ETSI Agrónomos, Universidad Politécnica de Madrid, Spain*

[d] *Laboratorio de Propiedades Físicas y Tecnologías Avanzadas en Agroalimentación, Universidad Politécnica de Madrid, CEI-Campus Moncloa. ETSI Agrónomos, Edificio Motores, Avda. Complutense s/n, 28040 Madrid, Spain*

ARTICLE INFO

Article history:
Received 12 August 2013
Received in revised form 14 January 2014
Accepted 20 January 2014

Keywords:
Cold chain
Monitoring
Logistics
Temperature sensors
RFID
Wireless sensors

ABSTRACT

Wireless Sensor Networks (WSN) and Radio Frequency Identification (RFID) are two wireless technologies that are being used for cold chain monitoring and tracking. Several applications in this field have been reported in the last few years. However, there are no studies about the the dynamic behavior of this hardware and how this affects the measurements. Therefore the purpose of this study is to evaluate the dynamic behavior of the sensors. A series of trials were designed and performed, covering temperature steps between cold chamber (5 °C), room temperature (23 °C) and heated environment (35 °C). Three WSN motes, with different sensor configurations, and four RFID tags (with and without housing), were compared. In order to assess the dynamic behavior two alternative methods have been applied for adjusting experimental data to a first order dynamic response that allows extracting the time response (τ) and corresponding determination coefficient (r^2). The shortest response time (10.4 s) is found for one of the RFID semi-passive tags. Its encapsulated version provides a significantly higher response (60.0 s), both times are obtained with the same method. The longest τ corresponds to one of the sensors embedded in a WSN mote (308.2 s). We found that the dynamic response of temperature sensors within wireless and RFID nodes is dramatically influenced by the way they are housed (to protect them from the environment); its characterization is basically to allow monitoring of high rate temperature changes and to certify the cold chain.

1. Introduction

WSN and RFID are changing and entering a new phase in the agro-food sector. A notorious advantage of wireless transmission is a significant reduction and simplification in wiring and harness. Many applications of wireless systems are being developed, such as: traceability by means of RFID, food packaging, history checking and contamination, or inventory control and food inspection (Wang et al., 2006; Ruiz-Garcia and Lunadei, 2011).

Relevant environments for the application of wireless systems include monitoring of fruit and vegetable containers and cold-storage facilities, or monitoring quality and senescence of specialty crops during transport (Ruiz-Garcia et al., 2009). The economic impact of product losses stays around 10% in Europe (6–7% in retailers) and 15% in USA (Pang et al., 2012), while reaching 30% in developing countries (mostly to the lack of temperature control). In either case, with transport distances above several thousand kilometers (Jedermann et al., 2011).

Food chains have become highly distributed, heterogeneous, cooperative, and globalized with extremely diverse requirements, and thus declares the need for convergence of all the necessary technical requirements (with dedicated analysis for wireless technologies), corresponding operation models, networking protocols, hardware (WSN vs RFID), and software. According to the authors (Pang et al., 2012), a scenario is an abstraction of a class of deployment environments, and so a particular scenario may appear multiple times at different positions among the entire sequence link, from produce and manufacturers to sellers or consumers (Pang et al., 2012).

These technologies are being used for cold chain monitoring and tracking. WSN motes have been validated for their use under cooling conditions in warehouses, studying the behavior of the

---

* Corresponding author. Tel.: +1 8636609984.
E-mail address: ricardobadia@live.com (R. Badia-Melis).

http://dx.doi.org/10.1016/j.compag.2014.01.014

motes in fruit chambers and then tested in refrigerated trucks during international transportation (Ruiz-Garcia et al., 2008, 2010). The fresh fish logistic chain has been also monitored using wireless sensing technologies (Hayes et al., 2005; Abad et al., 2009). RFID semi-passive tags were validated for monitoring cold chain in refrigerated trucks (Jedermann et al., 2009) and also for temperature tracking in a commercial shipment of pineapples from Costa Rica to the USA (Amador et al., 2009). Jedermann et al., 2011 focus mainly in the use of WSN in transport, and more precisely in the high attenuation of signal in packed food which has turned out to be the major problem for monitoring packed food transports. According to the authors, about 20% of the sensor data are lost because there is no physical route possible between a sensor node and the base station, while additional sensor data are lost because the protocols are not able to detect the correct routing (4% of the sensor data). Another conclusion of this study is the fact that electronics has to be protected against high humidity, condensed water, and mechanical stress during transshipments, while automated localization of the sensors inside the container could be very useful, because it cannot be guaranteed that the workers in the packing station may report the sensor positions properly (Jedermann et al., 2011). The sensors need protection against damage but at the same time this protection affects the way they respond to changes in the environment.

In the cold chain, perishable food products must be at controlled temperature during all stages. Sometimes, during transitions (like airport runaways, container docks, etc.) or incorrect handling (like unloading in non-refrigerated ambience) the products can change very quickly from one cool ambience to another that is not refrigerated. In a hot country, that could mean a difference of tens of degrees in just few seconds (Bogataj et al., 2005). Up to consumption, potential problems may occur in any phase: loading, unloading, handling and storage. Products can exceed the upper or lower limits with significant deviations from optimal conditions. Delays during loading and unloading are very common; products are exposed to not proper temperatures, reducing the shelf life or producing chilling injury in the products (Likar and Jevšnik, 2006; Montanari, 2008).

For example, ice cream should be maintained around −20 °C, but in a country like Spain outside temperatures can raise up to 40 °C. That means 60 °C of difference between inside and outside temperature. Thus inappropriate unloading of the product can happen very quickly. However, it takes longer time to the sensor to realize actual temperature, and the product can be spoiled by the time it gets that temperature. How long will the sensor take to measure the real temperature? Will it be fast enough? Are WSN and RFID ready for measuring the cold traceability of the products? Are they able to capture the real temperatures during loading and unloading?

In many occasions sensor nodes require a specific housing to protect the electronics from harsh environmental conditions, since this kind of equipment was not originally designed for those conditions, i.e. meteorological data acquisition system (Lee et al., 2010), however this effort always shows as contra wise effect, the lack of sensitivity of sensors.

Up to date there is no scientific information available about the dynamic behavior of WSN and RFID as related to sensor housing or mounting in the base electronics. The aim of this study is therefore to assess the dynamic behavior of the sensors because it is crucial for a proper characterization of history reconstruction.

2. Material and methods

A series of trials were designed and performed using WSN and RFID devices. The experimental work covers three different situations: cooling (5 °C), ambient temperature (23 °C) and heated environment (stove at 35 °C).

These tests involve two types of wireless ZigBee motes: IRIS and NLAZA. In the case of NLAZA one of the motes included a temperature sensor Sensirion embedded in the motherboard while the other mote has the sensor at the end of a cable (aerial mount, see Fig. 1). Besides, the IRIS module is provided, in this study, with a Sensirion and Intersema sensors; finally, four different RFID tags have also been used: two Turbo Tag 702-B (one with the default cover from the factory and the other one without that cover) and two Turbo Tag 700 (with the cover and without the cover as well); covers will also be referred as sensor housing further in the text.

2.1. WSN motes

The first type of motes have a microcontroller board (IRIS) together with an independent transducer board (MTS400) attached by means of a 52 pin connector. Its processor and radio platform is a XM2110CA. The RF power was configured to 3 dBm. Power was supplied by two AA alcaline batteries.

The MTS400 board hosts a variety of sensors: temperature and relative humidity (Sensirion SHT), barometric pressure and temperature (Intersema MS5534B), light intensity (TAOS TSL2550D) and a two-axis accelerometer (ADXL202JE). A laptop computer is used as the receiver, and communicates with the nodes through a Mica Z mounted on the MIB520 ZigBee/USB gateway board; this device also provides a USB programming interface. In this study the data from Sensirion and Intersema are used.

The Sensirion SHT is a single-chip relative humidity and temperature multi-sensor module that delivers a calibrated digital output. Each SHT is individually calibrated in a precision humidity chamber. The calibration coefficients are programmed into the OTP (One Time Programmable) memory. These coefficients are used internally during measurements to calibrate the signals from the sensors.

For temperatures significantly different from 25 °C, and according to the manufacturer recommendation, compensation is performed based on humidity and temperature.

The Intersema MS5534B is a SMD-hybrid device including a piezoresistive pressure sensor and an ADC-Interface IC data encoding that makes use of a 16 bit data word from a pressure and T (−40 to 125 °C ± 2.0 °C) dependent voltage. Additionally the module contains six readable coefficients for a highly accurate software calibration of the sensor.

The NLAZA motes include a sensor Sensirion SHT which measures temperature in the range -40 °C to 125 °C with a precision of ± 0.3 °C and from 0% to 100% (±2.0%) relative humidity. The mote communicates with a wireless hub by the ZigBee protocol. Data

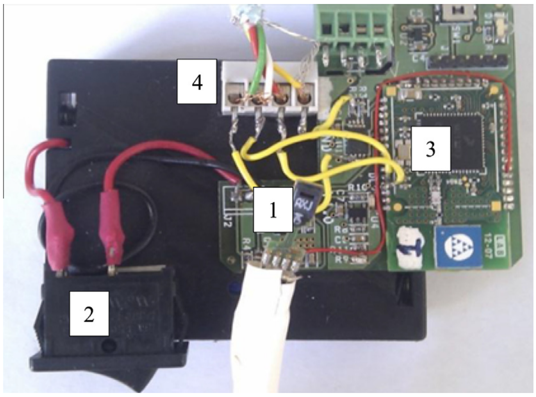


Fig. 1. Nlaza module with the temperature sensor mounted at the end of a cable.