Computers and Electronics in Agriculture 76 (2011) 252–265

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

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

Original papers

A novel methodology for the monitoring of the agricultural production process based on wireless sensor networks

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ARTICLE INFO

Article history:
Received 28 July 2010
Received in revised form 20 January 2011
Accepted 14 February 2011

Keywords:
Wireless sensor networks
Agricultural monitoring
Ubiquitous computing
Development methodology
Winemaking

ABSTRACT

Precision agriculture is a field which provides one of the most suitable scenarios for the deployment of wireless sensor networks (WSNs). The particular characteristics of agricultural environments – which may vary significantly with location – make WSNs a key technology able to provide accurate knowledge to farmers. This knowledge represents a valuable resource because it enables real-time decision making with regard to issues such as establishing water saving policies while providing adequate irrigation and choosing the right time to harvest the fruit based on its maturity.

This article proposes a methodology consisting of a set of well-defined phases that cover the complete life cycle of WSN applications for agricultural monitoring. We have studied different existing real-world scenarios where WSNs are being applied. Based on this study we have discovered that there exist significant commonalities but no methodology that specifies the best practices that should be used in the general, crop-independent case. The lack of a general methodology negatively impacts the amount of effort, development time, and cost of developing applications.

1. Introduction

In recent years, wireless sensor networks (WSNs) have emerged as a promising technology in the field of embedded systems. A WSN connects the physical and computational world by monitoring environmental phenomena through ubiquitous devices called sensor nodes or *motes*. These networks are composed of many autonomous, cooperating, battery-powered, small-sized motes usually connected through wireless links and a communication *gateway* with capacity to forward data from the motes to a *base station* with high processing and storing capacities. The potential provided by the motes is based on the integration of different sensors, from simple – e.g. temperature, light, humidity – to complex – e.g. global positioning system, images, micro-radars. This makes it possible to monitor a wide range of environments with the purpose of providing accurate and up-to-date knowledge from the field (Akyildiz et al., 2002). Fig. 1 depicts a WSN composed of a set of sensor nodes, a gateway, and a base station.

Developing an application requires an extensive effort to identify the key requirements and decide which are the general tasks and how to implement them; all these steps are necessary and incur a significant time investment and considerable financial costs. For specific domains such as the one we are targeting is it feasible to envision a methodology for guiding the development and deployment of WSN applications in agricultural environments. Several projects have been presented in the literature which use WSNs in the agriculture domain. These works take a first step towards connecting agriculture and sensor networks technology but constitute isolated case studies where only a limited set of aspects of WSN research have been exploited. To the extent of our knowledge there exists no work that proposes to unify the global development process into a set of best practices that cover the whole lifetime of an application. We are proposing a methodology to guide the development of applications for the agricultural domain based on wireless sensor networks. Our methodology facilitates the interaction between heterogeneous groups from multidisciplinary sciences. We are leveraging the existing state-of-the-art to design a generic methodology which integrates best practices in agricultural applications based on WSNs. We have been actively involved in a Spanish Research Project named *Control Automatizado de Procesos Agrícolas* (COPA) – Automated Control of Agricultural Processes – whose aim is to design and implement a prototype application for vineyard monitoring using sensor networks. We have applied our methodology within the COPA project; this approach proved to considerably facilitate the development process. This hands-on experience proved to be an invaluable resource in the process of filling the gap between the way isolated applications are built in the field and a robust, customizable development approach.

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doi:10.1016/j.compag.2011.02.004

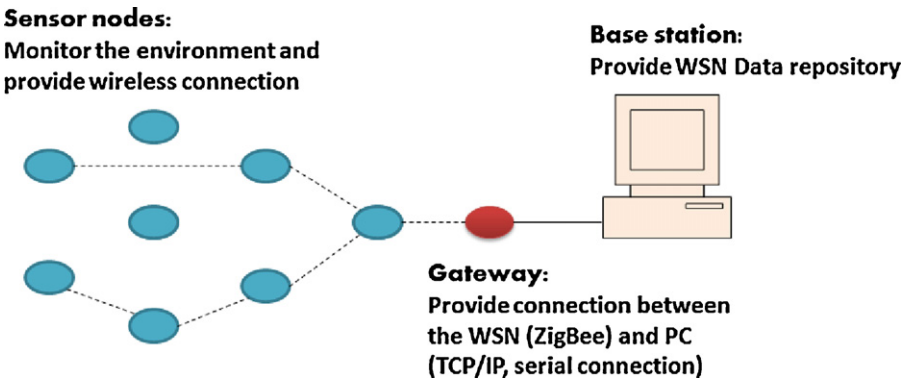

Fig. 1. A wireless sensor network.

The remainder of this paper is organized as follows. Section 2 describes the economic importance of the winemaking process as a reference sector of the Spanish economy and it discusses both WSNs and other alternative monitoring strategies. Section 3 presents the related work with regard to solutions for agricultural monitoring and decision making. In Section 4 we collect the general requirements for agricultural monitoring based on WSNs. Section 5 describes our proposal for a novel methodology designed to support applications development with the purpose of improving the agricultural production. Section 6 underscores our main contributions. We conclude in Section 7 by summarizing our work.

2. Motivation

2.1. Economic impact of the vineyard sector

Winemaking is an activity that brings a lot of income to the Spanish industry. Due to the type of monitoring and feedback that vineyards require they constitute one of the most suitable scenarios where sensor networks and embedded systems can help. COPA is a project intended for controlling vineyards with the purpose of improving the quality of the wine and it can be viewed as a representative example of monitoring application based on WSNs. We took advantage of the opportunity that COPA provides to directly quantify the impact of the methodology we are proposing in the field. As a result this paper focuses specifically on vineyard monitoring; our methodology can however be used to develop WSN applications to be deployed in other environments for other types of crops.

Due to the massive wine production both in Europe and world wide, 2004 brought with it a wine crisis which lead to a global reorganization of the vineyard production. The increase in the number of producers of wine in the European Union led to a reduction of the area dedicated to the grape production per producer. According to the International Organization of Vine and Wine (OIV, 2008) the rate of decrease is approximately around 40 thousands hectares per year. More wine providers make the market more competitive and quality becomes the key factor. Quality specialization is a critical factor for success and therefore competitors focus on factors affecting the quality of the wine. In Spain vineyards are considered a key sector for the country's economy. Spain is in fact the country with the largest extension of vineyard terrain in the world. The Spanish wine sector is important for its economic value and for the size of the population employed by this sector. The geographical situation, the climatic differences, and the variety of the soil make the peninsula a privileged place for producing wines with very distinct characteristics. In accordance with the Spanish Institute for Foreign Trade (ICEX, 2004) Spain has 62 Denominations of Origin.

The strict control of the wine production process is of utmost importance for obtaining wine of quality. Winemaking includes several phases which require distinct conditions depending on the type of grape: agricultural production, harvesting, crushing, fermentation, aging, and packaging. While some phases of winemaking can be supported by modern techniques, the agricultural production consisting of the cultivation of grapes and their surveillance is done with traditional techniques by the farmers in order to detect problems – e.g. plagues, humidity, or dryness – and ideal conditions – e.g. the Ph or sugar level.

2.2. WSNs in agriculture

WSN expert researchers agree that vineyards are a good candidate for the deployment of wireless sensor applications to monitor the vines and enable an informed decision process on the farmer's side. The winemaking process is affected by different factors such as weather – e.g. temperature, humidity, solar radiation – and particular conditions of the terrain – e.g. Ph, water content, topography. During the process of maturation of grapes, the photo-synthesis produces sugar, which is progressively stored in grapes. The balance among sugars, acids, Ph, potassium, and so on is fundamental to determine the quality of the wine. Another relevant aspect to consider is that the spatial variability of the conditions affecting the grapes is high. This means that vineyards located at short distances may measure notably different values for temperature, humidity, and so on due to factors such as the orientation and slope of the landscape. All of these factors can be monitored by deploying the appropriate sensor network. Real-time data from a sensor network deployed in the field may be used by experts to make decisions such as the irrigation policy, the location of vineyards onto raised posts to maximize the sunlight, or the actions to be taken when detecting fungus or plagues of the grapes. Additionally, WSN technology has the advantage of being both non-intrusive – in that wires are not required and there is no or little human intervention – and expected to become cheap in the near future.

2.3. Alternative monitoring strategies

There exist other alternative strategies that can be used for agricultural monitoring. The two main ones are:

- *Weather stations:* they provide accurate local measurements for various farming applications in real-time. Some measurements that can be obtained are wind speed and direction, temperature, pressure, rain level, and solar radiation. Some stations may also measure the ultraviolet index, leaf wetness, soil moisture, and soil temperature.
- *Surveillance satellites:* are used to harvest data from a terrain; in accordance with Economist (2009) this service costs about $15 per hectare for a handful of readings a year, while the benefits can increase up to 10%. Precise recommendations for growing crops