Agricultural Water Management 151 (2015) 64–74

Contents lists available at ScienceDirect

Agricultural Water Management

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

A wireless sensors architecture for efficient irrigation water management

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ARTICLE INFO

Article history:
Available online 1 November 2014

Keywords:
Remote monitoring
Wireless sensors
GPRS communication
Water optimization
Irrigation management

ABSTRACT

Water is an essential resource for the development of agriculture. In several locations like the southeast of Spain water is scarce and its cost is high, so optimal management of this important resource is essential. Therefore, the application of irrigation strategies to improve the watering process, affects the profitability of crops quite significantly. It is necessary to carry out the instrumentation of the variables that affect the growing process of the crop (soil, water and plant) and use the techniques associated with this instrumentation to take actions to optimize the production. The system proposed in this paper uses information and communication technologies, allowing the user to consult and analyze the information obtained by different sensors from any device (computer, mobile phone or tablet) in an easy and comfortable way. The proposed architecture is based on different wireless nodes equipped with GPRS connectivity. Each wireless node is completely autonomous and makes use of solar energy, giving it virtually unlimited autonomy. Different commercial sensors for measuring the wide range of parameters of the soil, plant and atmosphere can be connected to the nodes. The data is sent and processed on a remote server, which stores the information of the sensors in a database, allowing further consultation and analysis of data in a simple and versatile way.

1. Introduction

Irrigated agriculture is the biggest consumer of freshwater in arid and semi-arid zones, with a share of around 70–80% of the total volume of used water.

However, increased demand for water by other sectors and weather-associated limitations (increasing aridity as a result of climate change), suggests that the water resources available for agriculture in forthcoming decades will be lower in both quantity and quality. At the same time, new growers with lower production costs than the traditional ones in these areas are forcing them to reduce costs by lowering their main inputs. It is in this area of costs reduction where the efficient use of the water is becoming an increasingly important consideration, sometimes at the expense of crop quality. However such issues must be addressed if such crops are to remain competitive. It is a proven reality that in semiarid zones the limited availability of water has contributed to creating increasing interest in water conservation, particularly among practitioners of irrigated agriculture. For these and other reasons, the scientific- and technical-based irrigation scheduling of water to maintain and even improve yield and quality has been and will remain a major challenge for irrigated agriculture (Puerto et al., 2013).

In recent years, the incorporation of sensors in the context of agricultural production for water management and conservation has received an increasing interest for establishing irrigation management strategies, such as regulated deficit irrigation (RDI) or partial root drying (PRD). Both strategies allow very significant increases in irrigation water productivity (yield produced per unit of irrigation water applied), especially in woody crops (Egea et al., 2009; Jones, 2004; Puerto et al., 2013). However, these strategies need several sensors to estimate the plat water status.

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http://dx.doi.org/10.1016/j.agwat.2014.10.022
0378-3774/

Most common sensors to estimate plant water status are soil sensors, since they provide important information that is familiar to the user. These sensors provide data of the matric potential (Ψ_{m}, soil water status) or volumetric soil water content (θ_{v}, soil moisture). Over the years, these sensors have evolved significantly since the first manual gauges that measured the pressure of the soil water to become ever more effective and precise in measuring the soil's water status and moisture content, integrating communication with dataloggers (Fereres and Goldhamer, 1990; Hanson and Edwards, 2000).

In addition to these sensors, measures to control the volume or concentration of soluble salts in the irrigation water have often been used in irrigated agriculture, especially in arid and semi-arid areas. Water electrical conductivity (EC) is important, and irrigation water can be classified as running from excellent (EC $\leq$250 μS cm^{-1}) to unsuitable (EC $\geq$ 3000 μS cm^{-1}) (James et al., 1982). Moreover, it has been demonstrated that the crop production decreases as the EC of the irrigation water increases (Maas and Hoffman, 1977). The overall EC (or quality) of the used water can be adjusted by using water from different sources, which explains the use of sensors that provide measurements of the volume and quality of water held in reservoirs.

This type of sensor provides useful data for regulating the conditions required by each of these irrigation strategies. These sensors have been used in conjunction with instrumentation systems to control the irrigation process, traditionally with wired dataloggers. In recent years, the quick development of wireless sensor networks (WSNs) has led to the use of sensor equipment with very little wiring, and great improvements in their installation and maintenance (Hussain, 2012; Khan et al., 2014; Nolz et al., 2013; Ruiz-Garcia et al., 2009; Yu et al., 2013). Wireless sensor networks are composed of different measuring points, called nodes, able to communicate wirelessly. The data obtained from each one of them, is stored in a sink node and processed for managing irrigation.

The ultimate aim is to use the data from field sensors towards a fully automatic irrigation system. Although a fully automatic system has not yet been achieved, remote irrigation management is possible by means of routers and Internet connections that access the data collected by dataloggers (wired) or by the sink nodes (WSNs) (Puerto et al., 2013). The common point of these systems is that they have a centralized communication structure, that is, they depend on a device (gateway) to communicate with the user, which can lead to connection problems for the whole system if such a device has limited connectivity.

Advances in mobile networks and cheaper Internet communications (GSM/GPRS, 3G) has led in recent years to the incorporation of modules that provide WSNs with access to mobile networks by using machine-to-machine (M2M) modules. This feature provides more flexibility in the installation, as it is not limited by the connectivity of the sink node or datalogger. Each node contains a mobile communication module (GSM/GPRS, 3G) changing the topology of the network from centralized to distributed. One of the important advantage of this approach is that a connection failure at a node does not affect the normal operation of the network. However, the higher energy requirements of the mobile communications network represent a complex challenge for the design and dimensioning of the instrumentation of the nodes (Sinduja and Sowmya, 2013).

This article describes the design and dimensioning of a wireless node to fulfill the specified requirements of autonomy and reliability, allowing an easy installation and the ability to use the wide range of electrical interfaces in agronomic sensors. The results obtained in different agricultural scenarios are then used to verify the operation of the equipment and the goodness of the agronomic data.

2. Materials and methods

2.1. Hardware description

One of the most important aspects to consider when designing a device for monitoring any kind of variable is the ability to cover a wide range of significant parameters for the monitored activity that will provide the device with the versatility necessary for use in a broad variety of real situations. Such measurements are provided by specific sensors that are connected to the device by means of a wide range of possible connection interfaces.

In the present article, a completely autonomous device for estimating the plant water status in several scenarios is presented. The device, which must be compatible with a wide variety of sensors that provide plant-related data, is based on a modular structure that consists of several electronic interconnected boards:

1. An electronic board, the Main-Board, which has already been used in other applications, including oceanographic monitoring by means of a ZigBee network (Albaladejo et al., 2012). This board is responsible for sensors' data. It is also in charge of communication with the rest of the boards and ensures that the whole system is working properly.
2. The Sensor-Board provides the interface with the connected sensors. The design of the board is optimized for agricultural monitoring, allowing the simultaneous connection of a common precision agriculture sensors.
3. The GPRS-Board is in charge of establishing the communication with the mobile network by means of a GSM/GPRS protocol, sending the data to the remote storage server for further consultation.

2.2. Control, management and data collection subsystem

Fig. 1 shows the flow diagram of the Main-board. When it is powered up, the microcontroller obtains the configuration information from the SD-Card. This card contains information about the sensors connected to the Sensor-Board, the sample period and transmission rate, the GPRS and remote server configurations, etc. By simply modifying a few files, the user is able to completely change the behaviour of the system, providing great flexibility. As soon as the configuration is initialized, the system enters in a sleep mode in which the power consumption kept below 600 μA. When the sample rate time has expired, the microcontroller is "woken up" by an interrupt signal and the process of retrieving the information from the sensors starts. This process is carried out by the interface board. Then, the microcontroller obtains the time from the RTC and stores all the information in the SD-Card. Next, the system enters the sleep mode again and waits for another interrupt. When the sending rate time has expired, the Main-Board establishes communication with the GPRS-Board to send the information obtained from the sensors to the remote server. This board also performs a charging algorithm to optimize battery life, activating and deactivating a circuit in the Sensor-Board with the purpose of connecting the solar panel only when the battery is outside a specified voltage range.

2.3. Sensor interface subsystem

The Sensor-Board is one of the most important parts of the whole system since it provides the interfaces that will determine compatibility with external sensors. Given that the SDI-12 interface is one of the most important and standardized interfaces in the field of precision agriculture (López et al., 2009), it provides great flexibility because a wide range of commercial sensors used in agriculture are compatible with it. According to the technical characteristics