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Research Paper

Open source hardware to monitor environmental parameters in precision agriculture

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Precision agriculture combines the use of information and technology to ensure the best agricultural practices. Obtaining real-time non-invasive information to monitor crops or make yield predictions is a challenge. An approach is to use crop yield models in combination with real-time data used as input in such models. It was demonstrated that it is possible to design an accurate system using open source hardware and open systems to record the input for these models and monitor crops. The system presented has two main components: a device that records environmental parameters and a smartphone application (software) that links this device to a data server in order to process and analyse the information. The solution is scalable in terms of the type of sensors used (i.e. temperature and relative humidity of the air or soil), the rate of information retrieval and so on, so it can be used in various scenarios, including environmental or land policy monitoring. Moreover, this open source hardware can be used by a broad variety of users and is an alternative in poor rural areas because of its low cost compared to other solutions. It can enable increased agricultural production and management of the local environment, bringing new agricultural practices to these areas. Furthermore, progress in the use of this type of technology can help to develop new capabilities for growers. Results of calibration tests and measurements to demonstrate the usefulness of this system in precision agriculture are presented.

1. Introduction

Precision agriculture (PA) can be considered as the art, and science, of using advanced technology to enhance crop production. Its main goals are to tailor management practices to a crop considering the conditions of the site and to improve field management in order to minimise diseases and pests and consequently reduces the use of pesticides, leading to more efficient and environmentally acceptable agriculture (Blackmore, Wheeler, & Earl, 1996). Therefore, PA can be considered as a management strategy that uses information technology with the aim of improving production and quality (Valente et al., 2011). Obtaining real-time non-invasive information to monitor crops or make yield predictions is a

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Nomenclature

PA	precision agriculture
CM	crop model
GNSS	global navigation satellite system
IDE	integrated development environments
OSH	open source hardware
OSH-WS	open source hardware – weather station
OSS	open source software
RMSE	root mean square error
WSN	wireless sensor network
ANOVA	analysis of variance

challenge in agriculture. Crop models (CMs) offer reliable results and are interesting tools in PA, supporting decision-making in agriculture (Ewert et al., 2011). Climatic data are often the most important input data in CMs. Specifically, air temperature and precipitation are the most important climatic variables that influence yield (Porter & Semenov, 2005).

Even when mean values are used, predictions can be affected by fluctuations in temperature and/or precipitation (Semenov & Porter, 1995). The accuracy of CMs depends on the degree of knowledge of the weather conditions. This knowledge can be associated to a local area and even to an individual plot when the damage caused by frost in some crops is related to minimum temperatures that depend on the location and aspect of the plot. Under such scenarios it is necessary to determine environmental parameters for a specific plot. For example, crops such as tea are highly sensitive to these circumstances (Lou & Sun, 2013). In those situations, a specific plot may be affected by frost while a neighbouring plot may not. To determine the values of climatic variables, some regions have public weather station networks whose data are accessible to users. Although this information is useful, such stations are often remote from experimental sites and in-field environments (Bellocchi, Rivington, Donatelli, & Matthews, 2010), which reduces the usefulness of the data they provide. Moreover, the information usually refers to a broad area, so it is not possible to monitor different sectors in a plot using a network of sensors.

Recent progress in electronics, wireless communications and production of small size sensors provides new opportunities to monitor and control homes, cities, crops and the environment (Vieira, Coelho, da Silva, & da Mata, 2003). Wireless sensor network (WSN) technologies are the greatest driver of the development of precision agriculture. WSNs comprise several components called nodes. WSN nodes are smart devices that contain several sensors. A sensor is a device that is able to measure physical attributes and convert them into signals for the user. Sensors are the essential components of WSNs and therefore of the overall system for environmental monitoring and control. The development of WSN applications in PA makes it possible to increase efficiency, productivity and profitability while minimising impacts on wildlife and the environment (Srbinovska, Gavrovski, Dimcev, Krkoleva, & Borozan, 2015). Such sensor networks have three basic functions: sensing, communicating and computing. Wireless communication technologies such as WiFi, Bluetooth or Zigbee can be used and each have different properties and capabilities such as data rate, range or cost. In PA, sensors and their networks are being used in fertilisation (Cugati, Miller, & Schueller, 2003; He, Wang, He, Dong, & Wang, 2011), irrigation (Vellidis, Tucker, Perry, Kvien, & Bednarz, 2008; Yunseop, Evans, & Iversen, 2008), horticulture (López et al., 2011; López Riquelme et al., 2009), greenhouse farming (Ahonen, Virrankoski, & Elmusrati, 2008; Zhou, Yang, Guo, Zhou, & Wang, 2007) and monitoring of livestock and pastures (Andonovic et al., 2010; Ru, Huan-Sheng, & Bai, 2011).

Data provided by weather stations located near plots are useful to obtain a good description of climatic variables. Although several solutions are described in the literature or available on the market, their functionality is usually limited as their cost is high and they have constant maintenance issues (Gaddam, Al-Hrooby, & Esmael, 2014). Open source hardware (OSH) can be an alternative to such solutions. PA is largely used in the context of large farms and usually implies soil monitoring. In developing countries, such technologies are used in greenhouse farming but have not been used so far in open farms by farmers with small and marginal holdings (Babu, 2013).

In contrast to open source software (OSS), OSH is quite new (Faugel & Bobkov, 2013). One of the most popular examples of OSH is Arduino. It was created in 2005 at the Interaction Design Institute, Ivrea, Italy as a system that allowed students to develop interactive designs. Arduino consists of a microcontroller set on a small printed circuit board; it is fitted with sockets to allow connection with external devices with digital and analogue input and output (Koenka, Sáiz, & Hauser, 2014). Soon after its creation, Arduino started to be used in hobby projects such as drones and robots (Bin & Justice, 2009; Ross, 2014) or 3D printers (Kostakis & Papachristou, 2014), but scientific applications quickly followed. Arduino has been used for a broad range of applications such as monitoring radiation levels at nuclear facilities (Gomaa, Adly, Sharshar, Safwat, & Ragai, 2013), biomedicine (Kornuta, Nipper, & Brandon Dixon, 2013) and pharmacology (Thomson & White, 2014). Several authors have used Arduino to monitor ambient conditions such as temperature or humidity. Gomes, Ferreira, and Ruano (2011) measure and predict temperature, Rodriguez et al. (2011) monitor temperature of data centres and Barroca et al. (2013) measured temperature and humidity inside structures.

The development of OSH is often for commercial markets and thus may have the stability, ruggedness, accuracy, for other applications. In this study a prototype of a system that is able to provide PA services based on OSH is presented. The main purpose of this system is to measure infield environmental parameters to use as input in CMs: temperature and humidity of air and temperature and humidity of soil. This paper focuses on the design, implementation and validation of the system. Survey data are presented to assess the usefulness of the system, comparing it to data from a proprietary weather station.

2. System overview

Figure 1 shows the conceptual model of the system. It had three main elements: a weather station developed with open