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Development and assessment of a network of water meters and rain gauges for determining the water balance. New SCADA monitoring software

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ABSTRACT

Currently the scarcity of water resources in certain areas of the Mediterranean coast, specifically in southeastern Spain, make the irrigation efficiency a vital issue when it comes to cope with the high costs of water and contribute to an environmentally-sustainable and energy-efficient agriculture.

The aim of this paper is to describe the design and assessment of a system to determine the water balance of an experimental planting of four rows of eight pots of vines (*Vitis vinifera* L. cv Bobal). This system consisted of a network of low cost water meters and rain gauges and a supervision, control and datalogging application (SCADA) running in a compact programmable automation controller. The water meters were installed at the beginning of the rows to measure the irrigation water. Due to the low flow rate in the drainage network and given the scarcity and high price of low-flow rate flowmeters, we decided to study the feasibility of using tipping bucket rain gauges to measure the drainage water. For this reason comprehensive calibration tests were conducted to ensure their proper operation under the desired flow rate taking into account possible tilt variations in its field deployment. Data from flow meters and rain gauges were processed in the compact controller that was responsible for monitoring and generating charts in real time providing an interface accessible from the Internet. The historical data were sent to a remote FTP to have a backup and make them available from anywhere through an Internet connection. The results obtained during the system operation showed that it provided acceptable accuracy in the determination of water balance. This makes it feasible for applications such as irrigation scheduling of potted crops at a lower cost than other systems that estimate crop evapotranspiration using climatic data such as Eddy-correlation and Bowen-ratio stations.

1. Introduction

The agromotic systems to manage water and energy resources are becoming wide spreading in the agri-food sector, providing a response to the needs of control and automation of production processes (El-Gafy and El-Ganzori, 2012; Faye et al., 1998; Wellens et al., 2013). These systems are used to increase the efficiency of such processes, contributing to improve their performance and minimizing potential energy and production losses that may arise therein. In most cases, the primary objective is to minimize the consumption of water to obtain maximum production. This is critical in areas such as the southeast of Spain, where the cost of water is so high that it could compromise the viability of farms. In addition, reducing water consumption implies reducing energy costs of pumping.

There are different approaches to manage irrigation saving water and energy. In most cases the objective is to determine crop evapotranspiration to work out how much water the crop needs (Allen et al., 2011). One option is to use the reference evapotranspiration (ET_O) and other climate data from nearby stations for irrigation scheduling (Álvarez et al., 2004; Hunsaker et al., 2011; Ma et al., 2006; Thysen and Detlefsen, 2006; Xu et al., 2011). In developed countries there are organizations, usually public, that

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maintain a network of agro-climatic stations distributed through their territory. These stations measure environmental data (radiation, temperature, wind speed, relative humidity, atmospheric pressure, precipitation, etc.). These data are used to calculate the hourly and daily reference crop evapotranspiration (ET_O) using the Food and Agriculture Organization (FAO) Penman–Monteith (PM) equation (Allen et al., 1998). ET_O is calculated for a reference crop of green grass of uniform height, actively growing and adequately watered (Allen et al., 1998). Hence to schedule the irrigation of a particular crop, first we have to work out its particular evapotranspiration (ET_C). ET_C can be determined using equation (1) provided the crop coefficient (K_C) is known:

$$ET_C = ET_O \times K_C \tag{1}$$

The crop coefficient (K_C) is calculated for each type of crop and soil, but it shows variations during the plant growth. Furthermore it varies with the weather (especially with the relative humidity) (Allen et al., 1998). This makes the calculation of the ET_C from ET_O a particular complex process which is most of the time inaccurate (Allen et al., 2011; Cruz-Blanco et al., 2014; Droogers and Allen, 2002; Hunsaker et al., 2006).

There are works in the literature that propose to install agro-climatic stations in the crop in which irrigation must be managed (Fernández-Pacheco et al., 2014; Molina-Martinez et al., 2012) in order to obtain more accurate ET_O data and ensure greater reliability in the determination of the ET_C. These stations can be used to predict pests and diseases, and thus help to correct any alterations in the crop.

The use of ET_O and K_C, either from data from nearby agro-climatic stations or located in the crop itself allows planning approximate irrigation strategies, but is not suitable for precision agriculture that requires a very accurate optimization of water use. An alternative is the combined use of an agro-climatic station with soil sensors (temperature, humidity and conductivity) for determining more accurate models for irrigation (Hunsaker et al., 2011; Patel et al., 2012; Zhong-shan et al., 2010).

All the above methods are based on the use of complex theoretical and mathematical models that calculate crop water needs from the ET_O, sometimes with the support of additional sensors. A totally different approach is to accurately measure the water needs of a reduced group of plants and then extrapolate them to the irrigation planning of the whole crop. This can be mainly done in two ways: (i) using weighing lysimeters or (ii) performing an accurate water balance.

The use of lysimeters is widespread, and numerous references can be found in the literature for both pot and soil lysimeters (Beeson, 2011; Howell et al., 1991; Misra et al., 2011; Phene et al., 1991, 1989; Ruiz-Canales et al., 2013; Tripler et al., 2012; Wenting et al., 2013; Yan et al., 2013). This type of equipment allows calculating the water balance with high precision, but they have the drawback of the high cost associated with the measuring equipment. In the case of pots it also involves the design and installation of structures to accommodate the load cells and their auxiliary elements. In the case of soil lysimeters, the cost of civil works is very high.

The second option is to measure accurately the inflow and drainage of the plants in order to determine the water balance and the water consumed by the plant. This solution is much more economical than weighing lysimetry (Poss et al., 2004) since the instrumentation (water meters or equivalent devices) is cheaper.

In this paper the development and implementation of system for measuring the overall water consumption in a given pot crop is shown. The system is based on a series of water meters and rain gauges connected to a programmable automation controller with a new monitoring SCADA software with remote access capabilities. This controller receives signals from sensors, and performs all the related tasks such as signal conditioning, data logging and representation on the user interface.

2. Materials and methods

The studies and system deployment were carried out on an experimental plot located in the province of Alicante and managed by the Miguel Hernández Technical University (Campus of Orihuela, Orihuela, Spain). The experimental plot was located at 38° 4′ 10.17″ north Latitude and 0° 59′ 6.81″ west Longitude (Fig. 1). This plot was 19 m over the sea level with a surface of 328 m^2.

As Fig. 2 illustrates, the pots were arranged in two irrigation zones each consisting of two rows of eight pots. Pots under study are outlined in white while those used to eliminate border effects (Allen et al., 1998; Davis et al., 2012; Langton, 1990) are outlined in red. These pots were irrigated independently from those under study. Main pipes (one per zone) had nominal diameters of 32 mm and secondary pipes (one per row) 16 mm, where four volumetric water meters were installed (as can be seen in detail of Fig. 3 left). Two 80 cm micropipes supplied water to potted *Vitis vinifera* L. cv Bobal. Each pot had two 4 l h^{-1} non-pressure compensating drippers. The soil around the plants trunk was covered with a plastic film to prevent evaporation (Fig. 3 left), therefore only the transpirative component of evapotranspiration was present. For each row, drainage water from each pot was collected by a plastic tank (22.5 l capacity) sealed to the pot. The tank was connected, through a 16 mm diameter pipe, to a main slope-buried pipe with a nominal diameter of 32 mm (Fig. 3 left). At the end of the main drain pipe a tap was placed to regulate the discharge flow rate. This tap poured the line drainage water to a low-cost rain gauge (less than 10€) placed in a manhole (Fig. 3 right). All pipes used in the facility were made of polyethylene. With these features the possibility of water evaporation in the drainage network was negligible.

An industrial real-time CompactRIO controller (cRIO-9076) from National Instruments was used for the data acquisition, data-logging, analysis and automation tasks. The controller combines an industrial real-time processor (400 MHz), a reconfigurable field-programmable gate array (FPGA) Spartan LX45 and has four slots for I/O modules. The cRIO-9076 provides 256 MB of DRAM for embedded operation and 512 MB of nonvolatile memory for data logging.

The controller also features a 10/100 Mb/s Ethernet port that can be used to conduct programmatic communication over the network and built-in HTTP/FTP servers and remote panel Web server for interfacing with HTML pages, files, and the user interface of embedded applications. The controller was connected to the Internet using a wireless client that was linked to the wireless router available in the facilities of the University of Orihuela where the experimental plot was located.

To collect signals from water meters and rain gauges, the digital input NI9421 module was selected, capable of interfacing up to 8 digital 12/24 Vdc inputs with a maximum sampling rate of 10 KHz.

The software application was developed using the LabVIEW graphical programming language from National Instruments, which offers an engineering environment to designers for developing hardware–software systems for measurement, test and control tasks (Larsen, 2010). In order to develop the program for the CompactRIO controller, the real-time module from National was used as well.

The implementation and deployment of the system was performed in three stages. First, calibration test of the system measuring devices (water meters and rain gauges) were performed. All laboratory tests were carried out under controlled temperature and relative humidity conditions. In the second phase, since non compensating drippers were used, distribution uniformity was