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Development of a visual monitoring system for water balance estimation of horticultural crops using low cost cameras

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ABSTRACT

The use of low cost cameras has been extended in all fields of technology in general, and agricultural applications in particular. Images provide useful information on the growing state of horticultural crops, which allow an accurate estimation of water balance and, hence, precise irrigation scheduling. In all of these cases, the temporary images of a crop can provide the percentage of green cover (PCG). This data is calibrated with the irrigation water amount that the crop needs for growing. Therefore, the use of visual monitoring systems in agriculture may reduce water consumption and increase productivity. In this paper, a novel system is presented using low cost cameras and a client-server architecture. It is composed of a set of inexpensive camera modules which communicate with a cloud computing server. Camera modules have been developed using open standard Arduino components; they are able to work independently, with their own connectivity, storage and power supply. On the other hand, the server is responsible for configuring these modules, performing computer vision algorithms and water balance estimation, storing all data in a secure database, and interacting with the user interface using the web. The final result is a complete and inexpensive system that allows continuous monitoring of the state of the crops, providing the user with valuable information about water balance for irrigation management. The proposed method achieves a high accuracy in the estimation of PGC, with an average error below 5%, requiring less than 2 s of processing time per image in the server. This is transformed into an error in the computation of the crop coefficient below 1%. Technical details on the hardware and software components of the system are presented. Finally, advantages and weaknesses of the proposed solution are discussed, drawing new lines for future research.

1. Introduction

The growing scarcity of fresh water and the increase of energy costs are two of the main challenges for the sustainability of production systems nowadays. This fact is prominent in agriculture, where most water consumption occurs (Smith and Urpelainen, 2016; Wong and Pecora, 2015; Spinoni et al., 2015), and especially in some areas such as in the Mediterranean basin (Chalghaf et al., 2015; Roca et al., 2016). In recent decades, great improvements in water and energy management have been achieved by applying information and communication technologies (ICT) to agronomic engineering, particularly in the field of irrigation systems.

One of these emerging applied technologies is photogrammetry, which can be defined as the science of making measurements from photographs. It has been shown that, with suitable photogrammetric systems, it is possible to optimize the use of water in irrigation management in agriculture (Lou et al., 2016; Escarabajal-Henarejos et al., 2015a). Moreover, computer vision techniques can be helpful in many other tasks, such as crop monitoring (Brillante et al., 2016; Lin et al., 2013), controlling the quality of vegetables and fruits (Donis-Gonzalez et al., 2016; Kodagali and Balaji, 2012), weed control (Arroyo et al., 2016; Slaughter et al., 2008), and reading QR codes in the field (Qian et al., 2015), among others.

Many advances have been developed by means of remote sensing, where satellite imagery is used to cover large areas all over the world (Ramírez-Cuesta et al., 2017; Odi-Lara et al., 2016; Sicre et al., 2014; Xu et al., 2010). However, they are very costly techniques, so some research works have proposed alternatives such

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as smartphones, lightweight drones, kites and other kinds of unmanned aerial vehicles (UAV) (Haghighattalab et al., 2016; Anderson et al., 2016; Chianucci et al., 2016; Torres et al., 2016).

In the case of intensive agriculture for small holdings, which works with smaller plots and a greater variety of crops, these technologies could fail to provide useful visual monitoring. In those situations, the installation of cameras on the ground is a feasible option to achieve precise visual crop monitoring (Schima et al., 2016; Escarabajal-Henarejos et al., 2015a; Fernández-Pacheco et al., 2014). The cameras could be included as an additional component of other existing devices, such as lysimeters or agroclimatic stations, or they could be installed independently. For this to be feasible and profitable, two basic requirements should be met: the cost of each camera sensor should be kept as low as possible; and the system should be based on an open standard architecture. These features enable reduced installation and maintenance cost, ease of integration with other system components, and the possibility of future extension.

In both kinds of applications, the percentage of green cover (PGC) of a crop can be obtained from photography, and can be calibrated with respect to the exact amount of irrigation water that a crop needs for growing. Therefore, the estimation of PGC – named by some author as the leaf area index (LAI), fraction of vegetation cover (Fc), or plant canopy coverage (PCC) – has received much attention in the literature recently (Viña et al., 2011). This fact has resulted in some free and public tools for PGC estimation, such as EasyPCC (Guo et al., 2017), Canopeo (Patrignani and Ochsner, 2015), and Easy Leaf Area (Easlon and Bloom, 2014). The techniques applied are usually based on pixel by pixel color classification, using vegetation color indices and different color spaces. For example, Guo et al. (2017) extract the 9 channels of spaces RGB, HSV and CIELab, and apply decision trees for color classification. The method of (Patrignani and Ochsner, 2015) is based on color ratios, such as red to green (R/G), blue to green (B/G) and excess green (2G–R–B) which are then thresholded by the user. Although these tools are very effective and freely available, they are offered in the form of interactive PC programs or portable apps, so they cannot be directly integrated into a web server.

The objective of the research reported in this paper is the development of a new system for visual monitoring of crops in intensive horticultural applications. The proposed system consists of different hardware and software components, whose final goal is to provide farm managers with accurate, useful and frequently updated information about the state and water balance of the crop and its irrigation requirements.

2. Materials and methods

The design principle follows the concept of a wireless sensor network (WSN), which is currently one of the most promising technologies in agriculture (Jiang et al., 2016; Guo et al., 2015; Ojha et al., 2015). The system is composed of a set low cost camera modules located in the field, which communicate by using the Internet with a cloud computing server. The camera modules are based on Arduino boards, that meet the requirements of low cost and open standards. They contain the minimal components necessary for capturing and transmitting the images obtained, by using extension shields. The required image resolution for a suitable processing should be at least QVGA (320×240 pixels) or higher, with a typical capture frequency not higher than 1 image per hour (normally one image a day), since plant changes occur very slowly. The cameras are to be placed in a stationary position near the zenith of the monitored area.

Since Arduino boards have a reduced computing capacity, photogrammetric analysis is performed on the cloud computing server. This server is also responsible for performing water balance calculations, storing all the information in a secure database, configuring the capture modules, and interacting with the user through a web application. The computer vision algorithms implemented in the server allow automatic rectification of the perspective distortion of the images, and robust estimation of the green coverage of soil, which are then used to obtain irrigation requirements. The ultimate purpose of the system is to reduce the use of water while optimizing crop quality and productivity.

The development of the proposed solution for visual crop monitoring and water balance estimation involves the integration of hardware, software and communication components. This section describes all these components, which have been chosen to meet the requirements of the desired system. First, the hardware for the camera sensor and the microcontroller board are presented, with a justification of their suitability and an exposition of their main features. Then, the methodological aspects of the software development process, which is based on an agile programming method, are discussed. Finally, the underlying computer vision algorithms for image analysis are introduced. These algorithms deal with the problems of perspective correction, markers detection, plant/soil segmentation and crop coefficient estimation.

2.1. Description of the hardware components

As stated before, the principles that have guided the hardware design for the visual monitoring system are low cost and open architecture. The first of these principles enables installation of multiple modules in order to improve crop sampling and robustness to individual failures, while the second allows for easy extension of the system and reproducibility by other researchers. Each capture module consists of two main elements: a low cost camera, and a single-board microcontroller that controls the camera and communicates with the server code.

The camera selected for the prototype system is an OV7670 (OmniVision Technologies, Santa Clara, CA, USA). The main reasons for this choice are its low cost, high availability in the market, ease of integration using open standards, and a good quality-price ratio. OV7670 has an image sensor of VGA resolution (640×480 pixels) integrated in a single chip of reduced size. It uses CMOS (Complementary metal-oxidesemiconductor) technology, and has a simple optics that can be focused manually by screwing or unscrewing. Fig. 1 shows an image of this sensor and other components.

The camera chip has a predefined set of 8 bit registers to control different capture parameters. They can be read or written using the Serial Camera Control Bus (SCCB), which is compatible with the I2C (Inter-Integrated Circuit) interface with a maximum clock frequency of 400 KHz. Some registers are related to the analog steps of capture, while others are used to control the digital processes. The most important parameters for analog image functions are:

- Automatic Exposure Control (AEC). This allows adjusting automatically the exposure setting according to the luminosity level of the scene. This is performed in the timing generation controller of the OV7670.
- Automatic Gain Control (AGC). This parameter sets the control of gain to automatic/manual mode, enabling to obtain images with enough contrast level.
- Automatic White Balancing (AWG). White balance is related with the relative weighting of the three channels, RGB, captured by the sensor. The techniques for automatic white balance are usually based on assumptions such as the *gray world*, which considers that the average of all colors in an image tends to gray.
- Automatic Black Level Calibration (ABLC). This register controls the calibration of the minimum level of the sensor corresponding to black color.