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Web application for analysis of digital photography in the estimation of irrigation requirements for lettuce crops

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ABSTRACT

Different studies in the field of agricultural engineering have successfully related irrigation needs of plants with the percentage of green cover in crop images, by using simple allometric equations. Therefore, the problem of segmenting plants from soil in digital images becomes a key component of many water management systems. The development of automatic computer vision algorithms avoids slow and expensive procedures which require the supervision of human experts. In this sense, color analysis techniques have shown to yield the best results in accuracy and efficiency. This paper describes the design and development of a new web application with two different color segmentation techniques to estimate the percentage of green cover. The system allows a remote monitoring of crops, including functionality to upload images, analyze images, database storage, and graphical visualization of the results. An extensive experimental validation of this tool has been carried out on a lettuce crop of variety 'Little Gem'. The two segmentation methods – based on probabilistic color models using histograms, and clustering in the RGB space using the fuzzy *c*-means algorithm – are compared with respect to a manual segmentation technique which allows the human expert to validate the outcome of the process for each image. The experimental results demonstrate the feasibility of these two automatic methods as substitutes of the supervised process. The first method achieves a relative error below 2.4% in the obtained segmentation, while the second method has an error below 4.8%. Both techniques require less than 1 s of processing time in the server. Equations to compute the crop coefficient parameter are also included and validated for the same kind of crop.

1. Introduction

It is well-known that the parameters typically used to measure the size of plants and other living organisms – such as the volume, weight, area, height, root depth, etc. – are closely interrelated. The branch of biology that deals with the study of these relationships is called allometry (Huxley and Teissier, 1936). In agricultural engineering, the availability of these allometric functions allows to obtain precise estimates of parameters which are difficult to measure directly, such as the biomass or evapotranspiration coefficients, by using other easily measurable values, such as the plant height, diameter or surface (Neukam et al., 2016; Pastor et al., 1984).

In the literature, there are numerous studies that relate irrigation needs of crops with other variables that are directly related to evapotranspiration (ETc), which is defined as the sum of evaporation and plant transpiration. This ETc is calculated as the product of the reference evapotranspiration (ETo) by the crop coefficient (Kc) (Allen and Pereira, 2009). Other authors have analyzed the relationship between Kc and the percentage of green coverage (PGC), also referred as the fraction of coverage (Fc), thus providing satisfactory estimates for ETc (Escarabajal-Henarejos et al., 2015a). PGC is defined as the fraction of soil covered by the crop canopy in a top view of the ground. Besides, other allometric studies in agronomy have resulted in approximate methods to obtain the plant height (Grant et al., 2012; Xu et al., 2010), or the root depth (Escarabajal-Henarejos et al., 2015b), also by means of the PGC.

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Therefore, the computation of PGC is a widely studied problem in the field of agricultural engineering research. Many techniques have been proposed so far to estimate it by using non-invasive and low-cost image processing and artificial vision methodologies. Among others, the approaches based on color segmentation have proved to perform best in applications on water management systems (García-Mateos et al., 2015). As stated before, the value of PGC is mainly related to the canopy of the plant (Odi-Lara et al., 2016). This canopy regulates mass and energy exchanges and controls the behavior of physiological processes in a plant (Ruthrof et al., 2016). The PGC is used to represent different functions of crop growth and development. With the use of digital photography in irrigation control and scheduling it is possible to obtain the related parameters for crop growth modelling and water requirements. Moreover, with this technology it is possible to analyze deficiencies in management and to quantify the excess in irrigation, among others (Escarabajal-Henarejos et al., 2015a,b).

The aim of the present research is to develop an executable web application that integrates color segmentation techniques for the calculation of the PGC, followed by the estimation of the crop coefficient and evapotranspiration using allometric functions previously calibrated for a crop of lettuce. Although there are many tools for image analysis and water management in agriculture, they are usually presented as PC programs or portable apps, without the benefit of having a centralized server for information storage and Internet access. The main novelty of the proposed approach is the integration of image processing, crop coefficients computations, centralized storage and remote access in a web server application. This application allows monitoring of the plants throughout the cropping cycle, being easily usable by the farm managers. In the feasibility analysis of this application, not only the accuracy of the measured parameters are considered, but also other important aspects that influence their practical applicability, such as cost, flexibility, automation and scalability, for the irrigation control of a real commercial farming.

The rest of the paper is organized as follows. In Section 2, the technologies used in the development of the web application, and the computer vision algorithms applied for the estimation of the parameters are presented. Then, Section 3 describes the proposed web application, and the experimental validation that has been carried out. Finally, the main conclusions and future research lines are outlined in Section 4.

2. Materials and methods

This section presents the methodological aspects in the design of the proposed system, and the materials and resources used on its development. First, the technical features and tools of the web solution are described. Then, the two methods considered for the segmentation of plants and soil in crop images, in order to estimate the percentage of green cover (PGC), are introduced. These techniques constitute the image analysis core of the process. Finally, the methodology used for the validation of the web application is presented, with a description of a manually supervised way for assessing the obtained PGC values.

2.1. Tools and technologies used in the web application

The web application runs on an average off-the-shelf PC with an AMD Quad Core Processor at 2 Ghz and 8 Gbytes of RAM, with a WAMP server installed (Agrawal and Gupta, 2014; Ramana and Prabhakar, 2005). This kind of servers consist of four main components: a Windows operating system (Microsoft Corporation, Redmond, Washington, USA); an Apache web server (The Apache Software Foundation, Forest Hill, Maryland, USA); a MySQL database (Oracle Corporation Redwood City, California, USA); and a PHP interpreter (PHP: Hypertext Processor, the PHP Group).

The system has been programmed in PHP, which is mainly focused on the programming of server-side scripts. PHP code is embedded into HTML pages, allowing web developers to write dynamically and quickly complex web pages. This feature enables performing actions such as collecting form data, generating dynamic page content, managing databases, or sending and receiving data in an easy way. For these reasons, it has become the open source scripting language of the world's most popular websites (Achour et al., 2015).

Additionally, in order to improve data exchange of the PHP module, the library CURL (Curl Corporation, 2008) has been used. This library is capable of handling input data in JSON format (JavaScript Object Notation) that can be read by any programming language, thus enabling the exchange of information between different technologies in clients and servers. The flexibility of PHP language allows executing scripts remotely. This way, crop photographs can be captured in the field and transmitted via HTML, in a POST format, to the WAMP server. The server is responsible for processing the images and managing data, without needing to have a computer system in situ. All the data is stored on a MySQL database in the server, and can be consulted using the developed web application.

Finally, PHP facilitates the importation of libraries developed in any programming language. This capability will be the basis to incorporate into the website libraries for image processing and segmentation, which are necessary to obtain PGC parameters from the photographs. For image editing purposes, the native PHP extension Imagick will be used for displaying, converting, and editing raster and vector image files. It can read and write over 200 image file formats through the ImageMagick API (ImageMagick Studio LLC). Regarding the algorithms for color segmentation of plants and soil, two different techniques have been added to the program. The first technique, developed in the research group, is based on a probabilistic classification using color histogram models (Hernández-Hernández et al., 2016). The second technique is an adaptation of the unsupervised classification algorithm with fuzzy *c*-means (Bezdek, 1973). Since these methods are the core of the proposed application, they are described in detail in the following subsections.

2.2. Probabilistic classification with color histogram models

The software ACPS (Automatic Classification of Plants and Soil) implements the color segmentation technique using histogram models proposed by García-Mateos et al. (2015) and is distributed by Telenatura E.B.T. ACPS is an intuitive and user-friendly tool for agricultural image analysis, which includes image trimming and color models training (Hernández-Hernández et al., 2016). The program contains several generic color models for plant/soil processing, and new models can be created by the user. For this purpose, the human expert must select between 2 and 10 sample images under the same conditions of the future use, and mark some regions of interest for each class defined. The training process is iterative, allowing the user to refine the result successively. The color space is not fixed in advance, but the optimum space is selected among the 9 color spaces considered: HLS, HSV, I1I2I3, L*a*b*, L*u*v*, TSL, XYZ, YCrCb and YUV. Another interesting feature is that the model only has to be trained once for each type of crop and capture conditions, not for every individual image. Fig. 1 depicts an example of the training process of the color model using ACPS software.

In essence, the process consists in testing the 9 color spaces, and the 7 possible combinations of 1, 2 or 3 channels. For example, in the XYZ space the combinations are {X; Y; Z; X-Y; X-Z; Y-Z; X-Y-Z}. Each of the 63 possibilities is validated in a cross-correlation