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Optimal color space selection method for plant/soil segmentation in agriculture

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ABSTRACT

Color analysis techniques in agriculture should be able to deal with non-trivial capture conditions such as shadows, noise, pixel saturation, low lighting, different varieties of crops and intrinsic parameters of the cameras. Previous studies have shown the importance of selecting the optimum color space for each application domain. This paper presents a new probabilistic approach to color processing capable not only to create optimum color models for the plant/soil segmentation, but also to select the most adequate color space for each problem. The system evaluates all the possible alternatives, producing color models in the optimum space and channels. Thereby, the dependences on the kind of crop, camera and capture conditions are avoided, since the method is adapted to the training conditions. The basis of the proposal is the use of non-parametric models for the probability density functions of plant/soil colors. The proposed method has been implemented and validated in a new software tool, called ACPS (Automatic Classification of Plants and Soil), thus proving its practical feasibility. The final purpose of this system is the analysis of the vegetal ground cover, in order to obtain the PGC (percentage of green cover) parameter. The ACPS software has been developed to be used by professionals, researchers, technicians and anyone working in the agricultural area. Furthermore, the models created can be exported to a defined file format which can be used in applications in the cloud, mobile devices and compact controllers that are currently being developed.

1. Introduction

The development of agricultural production in the 21st century could not be understood without the use of automation technologies, which are designed to ensure maximum productivity, with high quality and at minimum costs on the inputs. Furthermore, production systems and organizational methods should ensure proper use of the assets –particularly water resources–, raise the efficiency of the crops, and allow their better exploitation since operating costs of agricultural equipment are increasing (Ortuño et al., 2010).

In the current global context, the goal of agriculture is to maximize benefits in the social, environmental and economic fields; this means to provide an appropriate use of environmental resources, irrigation technologies and farming techniques (Gonçalves et al., 2011). Under this premise, precision agriculture has proven to be a solution for the proper use of water in production systems. Due to the decrease in the cost of technology and the development of new remote sensing modalities (Ahamed et al., 2012), it is nowadays possible to apply techniques of digital image processing for agriculture massively (Lorente et al., 2012).

The new breakthroughs in digital image processing provide excellent tools for accurately and efficiently measuring parameters that estimate the vegetation cover of agricultural crop images. Such tests can achieve very small errors of recognition, which makes the obtained results highly reliable (Richardson et al., 2001).

One of the fundamental challenges to be solved is the segmentation of plants and soil in crop images, i.e. detecting pixels belonging to vegetation or not (McCarthy et al., 2010; Shiraishi and Sumiya, 1996). With the computed result, the percentage of green cover (PGC) –a key parameter in agronomy– can be estimated;

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it can be defined as the percentage of ground covered by the crop canopy in a top view (Fernández-Pacheco et al., 2014). Different authors have described the relationships between the PGC and important variables such as the crop coefficient Kc (López-Urrea et al., 2009; Allen and Pereira, 2009; Hanson and May, 2005), the height of the plants (Fernández-Pacheco et al., 2014; Xu et al., 2010), and the root depth (Escarabajal-Henarejos et al., 2015), from which water requirements can be predicted.

For this purpose, color is a key feature that has been extensively applied in the recognition of plants, fruits, vegetables, etc. (Lin et al., 2013; Story et al., 2010; Slaughter et al., 2008; Dobrzański and Rybczyński, 2002). In this regard, several studies have shown the importance of selecting the optimum color space for each application domain (Luszczkiewicz-Piatek, 2014; Kakumanu et al., 2007). For example, among the color spaces most commonly used, RGB, rgb, HLS, HSV, YCrCb, YUV, L*a*b*, L*u*v*, TSL, I1I2I3 and XYZ were included by García-Mateos et al. (2015) in a comparative study about plant/soil segmentation of lettuce (*Lactuca sativa* L.) crops. L*a*b* was found to be the best color space for the studied species, with an accuracy of 99.2% correct classification. However, although similar conclusions were supported by other researchers (Luszczkiewicz-Piatek, 2014; Shih and Liu, 2005; Kumar et al., 2002), in general the optimum color space is dependent of the characteristics of each particular setting. On the other hand, some authors have proposed the application of specific 1D projections of the RGB space (Woebbecke et al., 1995) or color clustering methods (Steward et al., 2004).

Moreover, computer vision in outdoor conditions involves additional difficulties due to the possible appearance of shadows, over- or under-saturated pixels, low contrast in cloudy or rainy days, etc., as well as variations due to the implicit camera parameters. These factors could cause dramatic changes in the captured colors of crops and soil, hindering the computation of correct segmentations. As an example, Fig. 1 shows a few cases of these complex situations.

The aim of this research is to develop a new training method for the automatic selection of the optimal color space and combination of channels for each case of interest. In this way, no particular space should be assumed to be the best for all possible scenarios; the system is able to choose the one which produces the best results in terms of classification accuracy for each specific situation, according to data provided by the human expert. Therefore, the proposed method can be understood as a generalization of previous researches that are based on a given and fixed color space. The new technique is able to adapt to different kinds of objects, and can be applied to segment multiple classes. The developed program has been carefully designed considering the aspects of usability, friendliness and appearance of the graphical interface. A preliminary version of this software is presented at (Hernández-Hernández et al., 2015).

The rest of this paper is organized as follows. In Section 2, the selected color spaces, the underlying color classification technique, and the new training method are described in detail. Then, Section 3 presents the new software tool that implements the training and classification processes, with an experimental study. Finally, Section 4 contains the main conclusions of this work.

2. Materials and methods

This section introduces the proposed approach for color model training with selection of the optimum color space for the soil/plant segmentation. First, the color spaces considered for the study are briefly listed and presented. Then the probabilistic color classification technique, which constitutes the base of the algorithm, is formulated. And, finally, the new technique for automatic training is described in detail.

2.1. Color spaces analyzed

Color is a subjective sensation of the human beings, derived from the capability of our eyes –more specifically, the photoreceptors in our retinas known as cones– to capture light in different spectral ranges (Luszczkiewicz-Piatek, 2014). The different existing *color models* are mathematical representations of these subjective perceptions, which describe how to represent colors with a tuple of numerical values. The set of values generated by all possible tuples of each model is called the *color space*. Since most of them are non-linear transforms of the RGB space, the way in which colors are distributed in each model are greatly dissimilar.

In (García-Mateos et al., 2015) a total of 11 standard color spaces used in computer vision are analyzed and compared for the problem of automatic segmentation of lettuce plants. The best ones were found to be HLS, HSV, YCrCb, YUV, L*a*b*, L*u*v*, TSL, I1I2I3 and XYZ. Consequently, these 9 spaces have been selected for the present work, being discarded rgb and RGB, which produce

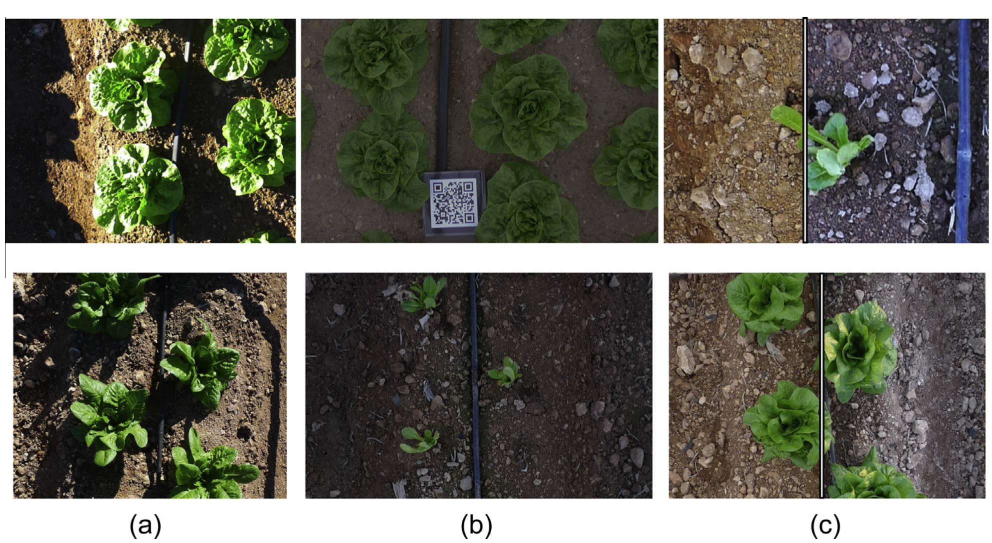

Fig. 1. Some examples of lettuce crop images that pose difficulties for color analysis. (a) Direct sunlight causing under- and over-saturated pixels. (b) Reduced contrast in a cloudy day and some spurious elements in the ground. (c) The same plots captured with two cameras with different white balances.