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A new Expert System for greenness identification in agricultural images

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ABSTRACT

It is well-known that one important issue emerging strongly in agriculture is related with the automation of tasks, where camera-based sensors play an important role. They provide images that must be conveniently processed. The most relevant image processing procedures require the identification of green plants, in our experiments they comes from barley and maize fields including weeds, so that some type of action can be carried out, including site-specific treatments with chemical products or mechanical manipulations.

The images come from outdoor environments, which are affected for a high variability of illumination conditions because of sunny or cloudy days or both with high rate of changes.

Several indices have been proposed in the literature for greenness identification, but under adverse environmental conditions most of them fail or do not work properly. This is true even for camera devices with auto-image white balance.

This paper proposes a new automatic and robust Expert System for greenness identification. It consists of two main modules: (1) decision making, based on image histogram analysis and (2) greenness identification, where two different strategies are proposed, the first based on classical greenness identification methods and the second inspired on the Fuzzy Clustering approach. The Expert System design as a whole makes a contribution, but the Fuzzy Clustering strategy makes the main finding of this paper. The system is tested for different images captured with several camera devices.

1. Introduction

1.1. Problem statement

Camera based devices is an excellent sensor for several applications. One of them is in agriculture where autonomous vehicles equipped with cameras are demanding solutions to distinguish plants (crops and weeds) with the aim of applying treatments over site-specific areas in a larger field (Davies, Casady, & Massey, 1998). Focusing on maize or barley fields, one of the most important treatments is weeds killing. Different methods and strategies for plant identification have been applied in different works (Burgos-Artizzu, Ribeiro, Tellaeche, Pajares, & Fernández-Quintanilla, 2009; Guerrero, Pajares, Montalvo, Romeo, & Guijarro, 2012; Guijarro et al. 2011; Montalvo et al., 2012; Onyango & Marchant, 2003; Tellaeche, Burgos-Artizzu, Pajares, & Ribeiro, 2008; Tellaeche, Burgos-Artizzu, Pajares, Ribeiro, & Fernández-Quintanilla, 2008). Lopez-Granados (2011) makes a revision of methods where plant identification is a key step in the process. Most existing strategies address the problem of green identification under the assumption that plants display a clear high degree of greenness. The images come from outdoor environments, which are affected for a high variability of illumination conditions: sunny or cloudy days or both with high rate of changes. In sunny days the position of the sun with respect the camera makes the illumination component impact differently and plants have different shades and shadows in the image. Furthermore, the greater the solar illumination the more intense infrared and ultraviolet radiations are. Also, high components of illumination could cause sensor saturation. These situations are absolutely normal in agricultural environments. Although modern camera devices have the ability to make auto image corrections through auto-image white balance or enhancement, most times this is insufficient, particularly in industrial cameras, where most camera settings must be dynamically adjusted (exposure time, auto-image white balance) or fixed in advance by the user (focal length, iris aperture).

This paper proposes a new automatic and robust Expert System for greenness identification which is able to cope with the identification of green plants even though adverse environmental conditions. It consists of two main modules: (1) decision making, based on histogram analysis and (2) greenness identification, where two different strategies are proposed, the first based on classical methods and the second inspired on the Fuzzy Clustering approach. The

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Expert System design as a whole and the Fuzzy Clustering strategy make the contributions of this paper. The performance of the method allows to verify its viability for automatic tasks in agriculture, involving the identification of green plants.

1.2. Revision of methods for greenness identification

Some years ago Tian and Slaughter (1998) considered the images captured under different conditions such as sunny or cloudy days, affecting illumination variability and assuming that they are typical situations in agricultural images coming from outdoor environments. Later several strategies have been proposed for segmenting crop canopy images, specifically oriented towards green segmentation:

(1) Visible spectral-index based, including the excess green index (ExG, Ribeiro, Fernández-Quintanilla, Barroso, & García-Alegre, 2005; Woebbecke, Meyer, von Bargen, & Mortensen, 1995), the excess red index (ExR, Meyer, Hindman, & Lakshmi, 1998), the color index of vegetation extraction (CIVE, Kataoka, Kaneko, Okamoto, & Hata, 2003), the excess green minus excess red index (ExGR, Neto, 2004) and the vegetative index (VEG) described in Hague, Tillet, and Wheeler (2006), which is designed to cope with the variability of natural daylight illumination. ExG, ExGR, CIVE and VEG have been applied under a combined form in Guijarro et al. (2011) gaining in performance with respect to their individual application. All these approaches need to fix a threshold for final segmentation, i.e. to discriminate between plants and other parts (soil, sky).

(2) Specific threshold-based approaches, including dynamic thresholding. Generally, these techniques assume a two-class problem where plants and soil are to be identified. Reid and Searcy (1987) estimate a decision function under the assumption that the classes follow Gaussian distributions. The Otsu's method (Otsu, 1979) is also applied considering a bi-class problem (Ling & Ruzhitsky, 1996; Shrestha, Steward, & Birrell, 2004). These algorithms are applied to gray images. Gebhardt, Schellberg, Lock, and Kaühbauch (2006) apply also thresholding for segmentation, and transform the images from RGB to gray scale intensity. This approach was later improved using local homogeneity and morphological operations in Gebhardt and Kaühbauch (2007). Kirk, Andersen, Thomsen, and Jørgensen (2009) apply a combination of greenness and intensity derived from the red and green spectral bands and compute an automatic threshold for a two-class problem assuming two Gaussian probability density functions associated to soil and vegetation respectively; this procedure requires the previous estimation of an angle to rotate the hypothetical greenness axis. Meyer and Camargo-Neto (2008) have applied the automatic Otsu's thresholding method for binarizing ExG and the normalized difference index (NDI), where a comparison is established against the segmentation obtained from ExGR determining that in this last case, a value of zero suffices for the threshold, therefore the Otsu's method is not required. Guijarro et al. (2011) and Burgos-Artizzu, Ribeiro, Guijarro, and Pajares (2011) have applied the statistical mean value of the transformed image obtained with the vegetation indices instead of automatic thresholding such as Otsu. They justify its choice because Otsu's method gives a threshold value higher than the mean and produces infra-segmentation, i.e. some plants are not conveniently identified.

(3) Learning-based, Meyer, Camargo-Neto, Jones, and Hindman (2004) have applied unsupervised approaches, including Fuzzy Clustering, for segmenting regions of interest from ExR and ExG. Tian and Slaughter (1998) proposed the environmentally adaptive segmentation algorithm (EASA) for detecting plants through a supervised learning process. Ruiz-Ruiz, Gómez-Gil, and Navas-Gracia (2009) applied the EASA under the HSI (hue-saturation-intensity) color space to deal with the illumination variability. Zheng, Zhang, and Wang (2009) and Zheng, Shi, and Zhang (2010) use a supervised mean-shift algorithm under the assumption that the segmentation of green vegetation from a background can be treated as a two-class segmentation problem; the class separability is validated through a neural network and the Fisher linear discriminant respectively, the color spaces used were RGB, LUV and HSI. Guerrero et al. (2012) apply Support vector machines as the learning.

1.3. Motivational research of the proposed strategy

The above methods are intended for plant identification through their greenness, based on the accentuation of the green color (Meyer & Camargo-Neto, 2008), but their effectiveness drops when, in the plants analyzed, the green spectral component loss its relevance because of adverse environmental conditions where such component takes similar values and sometimes lower than the red one.

Moreover agricultural images contain not only green plants but other structures, (soil, sky, debris, crop residues or shades), that must be conveniently addressed.

The main direct effect caused by the illumination is reflected in the image histogram, where the contrast is a decisive factor for greenness identification. Classical methods (ExG, ExGR, CIVE or VEG) work appropriately for well-contrasted images but fail miserably when images are insufficiently contrasted although they are later enhanced. This situation occurs most often in images captured with industrial cameras connected to a computer for image processing. Another undesired situation appears when important parts in the images become highly saturated.

Thus, our system is designed with a first decision making module based on image histogram analysis, which determines if the incoming image contains sufficient quality to apply classical greenness identification methods. Otherwise, the image is to be processed by a new greenness strategy, which is a method specifically developed with such purpose.

We focus this specific method as a bi-classification approach where green plants are considered as belonging to a class and the remainder elements in the image are assigned to the other class. The Fuzzy Clustering (FC) approach is conveniently adapted for this purpose. FC consists of two phases, namely: learning and classification. The learning phase is exploited to determine a dynamic threshold for each image and the classification is reduced to a simple decision making process. Previous to this process we apply image down sampling to achieve an image resolution with the aim of save processing time so that the image fulfil real time requirements if any.

Thus, the idea is to apply an automatic strategy for image segmentation based on the potential ability of the FC approach, where its learning phase is exploited to obtain a specific threshold valid for each image. No learning is required in the general sense; this avoids the need of prior training.

1.4. Paper organization

This paper is organized as follows. In Section 2 we explain the design of the proposed automatic Expert System with its stages and the corresponding image preprocessing procedures. In Section 3 the performance of the proposed strategy is evaluated. Finally in Section 4, the most relevant conclusions are extracted.