Computers and Electronics in Agriculture 118 (2015) 396–407

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Discrete wavelets transform for improving greenness image segmentation in agricultural images

M. Guijarro [a,*,1], I. Riomoros [b,1], G. Pajares [b], P. Zitinski [c]

[a] Department of Computer Architecture and Automatic, School of Computer Science, University Complutense of Madrid, Spain
[b] Department of Software Engineering and Artificial Intelligence, School of Computer Science, University Complutense of Madrid, Spain
[c] Department of Science and Technology, Linköping University, Sweden

ARTICLE INFO

Article history:
Received 6 February 2015
Received in revised form 7 September 2015
Accepted 11 September 2015

Keywords:
Textures
Image segmentation
Wavelets
Agricultural images
Thresholding
Binarization

ABSTRACT

We propose a segmentation strategy for agricultural images in order to successfully distinguish between both soil and green parts, the last ones including weeds and crop plants, based on discrete wavelets transform. Vegetation indices have been commonly used for greenness image segmentation, but improvements are still possible. In agricultural images weeds and crops plants display high spatial variability with irregular and random distributions. Textures descriptors have the ability to capture this information, which conveniently combined with vegetation indices improve the greenness segmentation results. The proposed approach consists of the following steps: (a) greenness extraction based on vegetation indices; (b) application of the wavelets transform to the resulting image, allowing the extraction of spatial structures in three bands (horizontal, vertical and diagonal) containing detailed information; (c) use of texture descriptors to capture the spatial variability in the three bands; (d) combination of greenness and texture information, in the approximation coefficients of the wavelets transform, for enhancing plants (weeds and crops) identification; and (e) application of an image thresholding method for final image identification. The wavelets transform allows both capture of spatial texture and its fusion with the greenness information, making the main contribution of this paper. This approach is especially useful when the quality of imaging greenness is low. It has been favorably compared against existing strategies, obtaining better results, quantified by 4,5%.

1. Introduction

1.1. Problem statement

A traditional tendency exists in the agricultural fields, when automatically applying pesticides onto the field, to apply them onto the entire surface, not to distinguish between soil and green parts (crop and weeds). This is an important issue, not only because of the waste of resources, but also because of the ecological impact.

Over the last years, and with the increasing development of computer vision and artificial intelligence techniques, along comes the concept of Precision Agriculture (PA), where an idea of selective application of pesticides onto agricultural fields is formed (Kropff et al., 1997). Keeping in mind that an automatization is mainly applied into considerably large fields where the investment makes sense, PA would imply a significant cost cut and a wise ecological decision.

Recently, important progress in agricultural field images processing has been achieved and automatic segmentation methods have been applied for identifying soil and green parts (crop and weeds) oriented toward PA (Ahmed et al., 2012; Montalvo et al., 2013). Nevertheless, because of the imaging systems work in unstructured outdoor environments with a broad variety of soil, crops and weeds, automatic image segmentation processes becomes a difficult task. The illumination effect represents an important handicap in real images. Indeed, as the atmospheric and daylight conditions change during the hours, one must bear in mind that the amount of light can differ significantly from one image to another, creating vast shadings in an image taken at late afternoon and bright colors in images acquired at a sunny day. For this reason Persson and Åstrand (2008), Guijarro et al. (2011) and Joycy and Prabavathy (2012) have addressed the problem providing different solutions taking account the shape or texture in order to avoid the impact of illumination variations. Other research line has been considered by Bai et al. (2014) where the objective is to

* Corresponding author.
E-mail addresses: mguijarro@ucm.es (M. Guijarro), pajares@ucm.es (G. Pajares).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.compag.2015.09.011
0168-1699/

improve the quality of vegetation segmentation for images captured under outdoor illumination.

This paper proposes a new approach for improving the image segmentation to deal conveniently the above difficulties dealing with green plants. It is based on a wavelet fusion-based strategy that exploits the performance of different segmentation methods and the power of wavelets to work under different resolution levels with the ability of capturing spatial texture distributions. The wavelets transform allows the combination of greenness and texture information, making this the main contribution of this paper, obtaining better results, quantified by 4,5%.

1.2. Revision of methods

Today most of the images that are processed are color images. So, the color segmentation techniques loom large. Throughout the decades, techniques for extracting information in color images are developed and described, as seen in Luccheseyz and Mitray (2001) and Zhang (1996).

In the scope of precision agriculture, color segmentation techniques are used in order to extract as much information as possible from the images. Thus, Zheng et al. (2009) used a new method, introducing a mean-shift procedure into the color segmentation algorithm improving the segmentation rate of the images. Another color segmentation is performed on Tian and Li (2004) where the binarization, in order to obtain the plant diseases, is done applying Fhiser criterion. In Zhang (1996) a supervised color image segmentation using a binary-coded genetic algorithm identifying a region in Hue–Saturation–Intensity color space, for outdoor field weed detection was successfully implemented.

Several methods, of these techniques, have been studied in order to develop a precise strategy for image segmentation oriented toward crop/weed detection in agricultural field images. According to Guijarro et al. (2011), the biggest issue, when it comes to computer vision, is image segmentation which has motivated the research conducted in this paper, where segmentation is oriented to successful green parts detection, through a new wavelets-based approach. Agricultural and forestry imaging segmentation has been considered through different strategies in the literature that can be categorized according to the specific differentiated method used:

(1) Visible spectral-index based, including the excess green index, *ExG*, (Woebbecke et al., 1995; Ribeiro et al., 2005), the excess red index, ExR, (Meyer et al., 1998b), the color index of vegetation extraction, CIVE, (Kataoka et al., 2003), and the excess green minus excess red index, ExGR, (Neto, 2004). And the vegetative index, VEG, described in Hague et al. (2006), which was designed to cope with the variability of natural daylight illumination. All these approaches need to fix a threshold for final segmentation.

(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) estimated a decision function under the assumption that the classes follow Gaussian distributions. The Otsu's method (Otsu, 1979) was also applied considering a bi-class problem, where the algorithms are applied to gray images. Gebhardt and Kaühbauch (2007) applied also thresholding for segmentation, transforming the images from RGB to gray scale intensity. This algorithm was later improved using local homogeneity and morphological operations. Kirk et al. (2009) applied 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 computes a first greenness feature for each pixel, *g*, as the decimal logarithm of the ratio between the red and green pixel values and a second brightness feature, *L*, for each pixel as the difference between the decimal logarithms of the green value and the mean value over the full image. Pixels are mapped on the (g,L)-space and the classification of each pixel is carried out by projecting the *g* and *L* magnitudes on a one-dimensional axis (variable) by applying a rotation angle α in the counter-clockwise direction as follows: $d = \cos(\alpha)g + \sin(\alpha)L$ with $\alpha > 0$. This method requires the previous estimation of α. Meyer and Camargo-Neto (2008) applied the automatic Otsu's thresholding method for binarizing *ExG* and the normalized difference index (NDI), where a comparison was 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. Gée et al. (2008) process the image in two steps. In the first step they applied a double Hough transform to the crop rows from their vanishing point and in the second one they obtain a region-based segmentation for discrimination the crop and weed. Burgos-Artizzu et al. (2011) do the binarization of the image with a vegetation index, using a threshold which is automatically set for each image. This threshold is adjusted evaluating two methods Otsu and the statistical mean value. They chose the statistical mean value in the resulting image obtained with the vegetation index, because Otsu gives a higher threshold value causing vegetation to be slightly reduced, i.e. infra-segmentation. Guijarro et al. (2011) choose the statistical mean value because of the same reason, with Otsu some plants are not conveniently identified. Montalvo et al. (2013) used a double Otsu thresholding, the first one is applied for binarizing *ExG* and to separate two types of plants with high and low degree of greenness. The first thresholding is used to separate the ones with high degree of greenness and the second for the ones with low greenness. A double thresholding was also applied in Montalvo et al. (2012) to discriminate between maize plants and weeds with high density, also under the assumption that crop and weeds displays different degrees of greenness. Romeo et al. (2013) proposed an algorithm to separate the green plants from the rest using fuzzy clustering in two phases, the learning phase is exploited to determine a dynamic threshold for each image and the classification is reduced to a simple decision making process. Samal et al. (2006) use the co-occurrence matrix to obtain the textural features values as can be energy, local homogeneity and inertia in order to establish a feature space and under the nearest-neighbor method is possible to distinguish trees from backgrounds. Also, Alchanatis et al. (2005) developed an algorithm which used spectral reflectance properties and statistics features for weed segmentation. This research was made with a hyperspectral sensor and they select two specific channels for distinguish soil and crop.

(3) Learning-based, Meyer et al. (2004) 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 et al. (2009) applied the EASA later under the HSI (Hue–Saturation–Intensity) color space to deal with the illumination variability. Zheng et al. (2009, 2010) used a supervised mean-shift algorithm under the assumption that the segmentation of green vegetation from a background can be treated as a two-class