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Analysis of natural images processing for the extraction of agricultural elements

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ABSTRACT

This work presents several developed computer-vision-based methods for the estimation of percentages of weed, crop and soil present in an image showing a region of interest of the crop field. The visual detection of weed, crop and soil is an arduous task due to physical similarities between weeds and crop and to the natural and therefore complex environments (with non-controlled illumination) encountered. The image processing was divided in three different stages at which each different agricultural element is extracted: (1) segmentation of vegetation against non-vegetation (soil), (2) crop row elimination (crop) and (3) weed extraction (weed). For each stage, different and interchangeable methods are proposed, each one using a series of input parameters which value can be changed for further refining the processing. A genetic algorithm was then used to find the best value of parameters and method combination for different sets of images. The whole system was tested on several images from different years and fields, resulting in an average correlation coefficient with real data (bio-mass) of 84%, with up to 96% correlation using the best methods on winter cereal images and of up to 84% on maize images. Moreover, the method's low computational complexity leads to the possibility, as future work, of adapting them to real-time processing.

1. Introduction

Precision Agriculture (PA) is a concept that addresses the in-field variability of factors that influence crop growth. It seeks to avoid applying same management practices to a crop regardless of site conditions. PA may be used to improve field management from several perspectives; for example it can help to minimise the wastage of products required for the effective control of weeds, diseases and pests and to ensure that crops receive adequate nutrients [1]. In this context, the benefits of site-specific management include a cost reduction to produce the crop and a reduction in environmental pollution [2].

In the generation of a treatment map it is essential to know the degree of weed coverage in each area of the field. To obtain this information, a sampling process is habitually carried out in the crop field whereby data are acquired for selected points (sampling points). The overall situation in the field is then inferred by means of an interpolation process.[1] A simple approach would be to perform photographic sampling of the crop field to then analyse the images with an image processing system, calculating the weed cover associated with each picture.

Since the beginnings of the PA, the gathering of visual information on the field has been performed in many different ways, strongly depending on the technology available at each period of time. The techniques used to gather information on the field can be divided into three main groups [4]: (1) by means of devices boarded on aircrafts; (2) by means of devices boarded on satellites; and (3) directly from ground level. The use of aircrafts appeared in the years 80, when the usual procedure was to take images with a near-infrared (NIR) camera boarded on the aircraft, and later analyzing the images to elaborate approximate maps of weed distribution [5,6]. In the'90 the use of images taken from satellites began, due to the appearance of GPS and the civil use of satellites. The use of both methods has always been very expensive, and difficult due to the fact that images can be taken only on optimal weather conditions. Moreover, the height from which the images are taken cause low precision images.

In the mid-late'90 these aerial methods fell in disuse due to the appearance of more advanced computers that permitted direct photo analysis, though nowadays are experiencing a resurgence due to the use of hyper and multispectral cameras, that facilitate and potentiate the reckoning of each species [7]. Still, these methods continue to show clear disadvantages like their high economic

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[1] The Kriging is the interpolation technique most used. A Kriging prediction is a weighted linear combination of all output values already observed. These weights depend on the distances between the input for which the output has to be predicted and the inputs already simulated [3].

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costs and low resolution due to the height from which images is taken, causing each pixel to represent more than a square meter of area.

Since technology allows it (late'90), the main tendency has been to try to develop weed detection methods starting from images taken at ground level, which provide sub-centimeter precisions. In this context and since its beginnings, computer vision techniques have begun to be used. Studies in this area take images of the field from diverse heights, usually inferior to 3 m, from tractors, agricultural robots, or simply by hand. In this context, research work is difficult to classify and compare due to the variations that each different crop presents.

Almost all the methods for weed detection, independently of the type of crop treated, have in common the first stage: segmentation of vegetation against background. The procedures for segmentation of the vegetation pixels usually take into account the fact that all pixel belonging to vegetation have a strong green component. This characteristic can be used directly through the RGB colour model or creating colour indices that represent the 'greeness' of a given pixel [8–15]. Other approaches propose the use of the HSI colour model combined with classification methods as Bayes networks or clustering [16–19]. Segmentation can also be performed by texture features selection and its similarities with previous models encountered, stored in a database [20,21]. Moreover, as was done in aerial images, segmentation can be performed by combination of different cameras, as conventional and NIR cameras [22].

After the vegetation has been separated from background, it is necessary to detect which of those vegetation pixels belong to weeds. Weed detection by computer vision methods is usually performed combining information about colour, position, shape, texture, size or spectrum of weeds. The use of only one or many of these characteristics depends on the way images are taken, crop type, and weed species involved.

For example, in lettuces crops, plants and weeds can be clearly distinguished by their differences in size (lettuces are much bigger), and position [19]. Something similar happens with cauliflowers, where weeds can be located by its position and some shape characteristics [23]. In carrots and cabbages crops, weeds have distinct differences in colour and size, which can be detected using discrimination methods [18], or by differences in the spectral reflectances [24].

However, in most of the crops one unique characteristic is usually not enough to discriminate between weeds and crop, since weeds present shapes and colours very similar to those of crop. In these cases a more complex study of the features of weeds is necessary.

Some works present statistical studies of the features involved [15,11,10]. Others choose to distinguish the species by their different spectrum, combining the information of the conventional camera with a NIR camera [22,25]. Having at disposal training images and knowing beforehand the weed species that can be present in the crop studied, different methods of classification by feature extraction can be used, including as many characteristics as necessary. To perform the classification, Bayes networks [16,17,26], or neuronal networks [12,27–29] can be used. Finally, some propose to process the images in the frequency domination [30,31] or even using Fuzzy Logic [13].

Another possible approach is to identify crop rows first, taking advantage of the evenly spatial layout they present. Crop row location is often a desirable goal in autonomous guidance of agricultural vehicles [32–34]. These studies are able to detect crop rows and use their location to successfully guide vehicles in the field in real-time. However, to be able to work in real-time, crop rows are only approximated, where for weed detection the precision required is much higher. As such, some works use the Hough transform to fully locate the crop rows and then label all the rest of vegetation pixels as weeds [35,36]. The drawback of this approach is the high computational complexity of the Hough transform, which makes it not suitable when processing a large number of images. Finally, some other studies start from more simple images, taken closer from the ground and in a way where perspective is eliminated and therefore crop rows can be more easily located (as is the case in this work) [37,38].

Unfortunately, none of these studies have resulted so far in commercialization of the technologies developed, even though it is a common global aim [39]. The major problems associated with this concern the high computing and economic costs involved, as well as the difficulties of correctly representing all the possible situations present in real and outdoor conditions (different uncontrolled illumination, state of crop growth, etc.).

The present work forms part of a research project aimed at developing a decision-making system based on the generation of weed control risk maps. In this project, emphasis has been placed on the development of data post-processing techniques to generate accurate maps. This paper presents the software developed for the image analysis stage. In particular, a computer-based image processing system has been implemented that allows the user to input digital images of a crop field, and to process these by a series of methods to enable the percentages of weed, crop and soil present in the image to be approximated. These percentages are subsequently used as a parameter to determine where to use herbicide and in what doses. In other words, the estimations are employed to generate a treatment map.

The rest of this paper is structured as follows. Section 2 presents briefly the problem. Section 3 describes the proposed image processing methods. Section 4 presents an analysis of the results obtained using a genetic algorithm, for a set of digital images that includes different illumination conditions. Section 5 outlines the conclusions obtained from the study.

2. Description of principal issues

Given any sample image, the system has to be able to compute the *Weed Pressure* (WP), as shown in Eq. (1). The *WP* can be used to measure the risk the weed represents, therefore being useful to decide the dosage of herbicide required [14]. *WP* at a point is expressed as a function of the percentages of weed cover (c_w), crop cover (c_c), and soil (c_s). Consequently the objective of the tool should be to help the user evaluate the relative percentages of weed, crop and soil.

$$WP = \frac{c_w}{c_c}(100 - c_s) \qquad (1)$$

All digital images used for this study were taken with Nikon Coolpix 5700 and Sony DCR PC110E cameras in barley fields on La Poveda Research Station, Arganda, Madrid. All images were taken on different days during the last four years, always on February and March, the usual dates for post-emergence herbicide applications. At these times, plants are in early tillering (February) and late tillering (March) stages. The most common weeds found were *Avena sterilis* and *Papaver rhoeas*. These weeds, at the time of herbicide applications, are indistinguishable from the crops in colour, shape and texture, so that the only possible method of discrimination left is its position (between crop rows).

In this context, the main challenge in terms of image analysis is to achieve an appropriate discrimination among weed, crop and soil in outdoor field images under varying conditions of illumination, soil background texture and crop damage. Moreover, the methods developed should be as simple as possible, looking towards the future development of a real-time spraying system. Therefore, to level out the task at hand, images are taken between