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Selecting patterns and features for between- and within- crop-row weed mapping using UAV-imagery

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ABSTRACT

This paper approaches the problem of weed mapping for precision agriculture, using imagery provided by Unmanned Aerial Vehicles (UAVs) from sunflower and maize crops. Precision agriculture referred to weed control is mainly based on the design of early post-emergence site-specific control treatments according to weed coverage, where one of the most important challenges is the spectral similarity of crop and weed pixels in early growth stages. Our work tackles this problem in the context of object-based image analysis (OBIA) by means of supervised machine learning methods combined with pattern and feature selection techniques, devising a strategy for alleviating the user intervention in the system while not compromising the accuracy. This work firstly proposes a method for choosing a set of training patterns via clustering techniques so as to consider a representative set of the whole field data spectrum for the classification method. Furthermore, a feature selection method is used to obtain the best discriminating features from a set of several statistics and measures of different nature. Results from this research show that the proposed method for pattern selection is suitable and leads to the construction of robust sets of data. The exploitation of different statistical, spatial and texture metrics represents a new avenue with huge potential for between and within crop-row weed mapping via UAV-imagery and shows good synergy when complemented with OBIA. Finally, there are some measures (specially those linked to vegetation indexes) that are of great influence for weed mapping in both sunflower and maize crops.

1. Introduction

Sunflower is nowadays the third most important herbaceous crop in Spain when considering cultivated area. Demand of its seeds and the high consumption of sunflower oil have consolidated the importance of this crop in the agriculture of Spain and other European countries. Maize also plays an important role in the Spanish fields (and worldwide, e.g. in the Mediterranean basin, Argentina–Brazil and the corn-belt in the USA, among others). The relevance of this crop worldwide comes from its wide uses.

Although the impact that these crops have in the Spanish agricultural sector is clear, weeds are usually responsible for a large reduction in potential crop yields (approximately 35%). Because of this, nowadays, most farmers in the EU rely on synthetic herbicides, usually providing a weed control efficacy of 75% (Oerke, 2006). The percentage of herbicides used in maize and sunflower with respect to the total of pesticides is large (86.5% for maize and 87.3% for sunflower), the optimised use of these herbicides being vital for the agricultural scenario. Although weeds are distributed in patches and there are very clear economical and environmental risks from the over-application of these herbicides, the most common procedure is to apply them to the whole field. The cost of these herbicides usually accounts for 40% of the cost of all of the chemicals applied to agricultural land in Europe (European Crop Protection Association (ECPA), 2015). This economic factor together with environmental concerns have led to the creation of the European legislation on the Sustainable Use of Pesticides (Horizon 2020; Regulation (EC) 1107/2009 and Directive 2009128/EC, 2009). The inclusion of these guidelines has been parallel to the introduction of patch spraying in the machinery, which has enabled the feasibility of site-specific weed management (SSWM) based on weed coverage maps obtained via ground sampling, proximal sensing or remote sensing. In this sense, the key component of

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SSWM is to provide precise and timely weed maps for an appropriate early weed control.

In early growth stages, the spectral and appearance characteristics of both crops and their infesting weeds are similar, thus imposing additional difficulties for their differentiation. The mapping of weeds has been addressed by most previous works by detecting weeds at late growth stage (e.g. flowering) using piloted aircrafts or QuickBird satellite imagery (Castillejo-González, Peña, Jurado-Expósito, Mesas-Carrascosa, & López-Granados, 2014; Gutiérrez, López-Granados, Peña Barragán, Jurado-Expósito, & Hervás-Martínez, 2008), although the spatial resolution of these platforms is not suitable for seedling detection (pixel size around 50 cm and 2.6 m for piloted aircrafts and QuickBird satellite, respectively). Nonetheless, a new aerial platform has recently joined the traditional ones, known as the Unmanned Aerial Vehicle (UAV) (Moranduzzo & Melgani, 2014). Different studies have highlighted the advantages of UAVs over airborne or satellite equipment (Lucieer, Turner, King, & Robinson, 2014; Peña, Torres-Sánchez, de Castro, Kelly, & López-Granados, 2013), specially a minor cost, a higher flexibility in flight scheduling and a better spatial resolution. These advantages make UAVs a very useful tool to perform field studies for crop and weed monitoring at early crop and weed phenological stage (Torres-Sánchez, López-Granados, De Castro, & Pena-Barragán, 2013), which is a classic limitation of the traditional remote sensing platforms.

Previous methods in the literature have been designed with the purpose of remote weed mapping using manually-defined rules and have shown great promise in detecting weeds between-crop-rows (Peña et al., 2013; Pérez-Ruiz, de Santos, Ribeiro, Fernandez-Quintanilla, Peruzzi, Vieri, Tomic & Agüera, 2015), but the identification of weeds within-crop-rows still remains an open challenge. The reason is that the algorithm designed for weed detection must be highly robust because very similar seedling crop and weed plants emerge mixed within the crop row. In this sense, this paper studies the use of supervised machine learning methods for constructing a model for weed identification. This is one of the main novelties of this paper, because machine learning methods have been mostly used with the purpose of remote vegetation mapping in on-ground studies (Burgos-Artizzu, Ribeiro, Guijarro, & Pajares, 2011; Tellaeche, Pajares, Burgos-Artizzu, & Ribeiro, 2011) or using piloted platforms but have uniquely been used with UAV-imagery in two preliminary works which showed the great potential of these techniques (Hung, Xu, & Sukkarieh, 2014; Pérez-Ortiz, Peña, Gutiérrez, Torres-Sánchez, Hervás-Martínez & López-Granados, 2015b). Our present work considers these previous results and tries to deal with some of the problems that have been identified when using object-based image analysis (Blaschke, 2010) (OBIA), a strategy that have shown better performance than the pixel-based approach in preliminary results (Pérez-Ortiz et al., 2015b). Roughly speaking, OBIA is devoted to the division of remote sensing imagery into meaningful sets of pixels (known as objects) which are considered as similar based on a measure of homogeneity (Blaschke, 2010).

In a preliminary conference work (Pérez-Ortiz, Gutiérrez, Peña, Torres-Sánchez, Hervás-Martínez & López-Granados, 2015a), a first hypothesis that we studied was whether OBIA provided more robust results and how many objects should be labelled. The results showed that OBIA was beneficial, both in terms of performance and computation time. This result was obtained only labelling 100 objects per class (randomly selecting objects and manually labelling them using three classes: soil, weeds and crop). The problem of this approach was that the size of the field image in this type of applications is usually large (and so is the number of objects produced), being difficult the selection of a representative set of patterns of the whole experimental field. In this way, our classification method encountered problems when classifying objects not contemplated in the described spectral range (e.g. rocks) (Pérez-Ortiz et al., 2015a) and demanded a lot of effort from the user to select a suitable training set of patterns. The results also showed that there were other features, apart from the mean and standard deviation of the object, that had a great impact in the classification and that the use of machine learning helped distinguishing weeds within-crop-rows and creating more robust learning models. Moreover, differences in performance occurred when factors such as flight height, sensor and classification method were considered. The results showed that the optimal flight height was 30 m using preferably a visible sensor and an advanced classification method.

In this paper, we extend the previously mentioned work by trying to answer additional questions. Firstly, whether it is possible to develop an automatic method to select the most representative objects of the field, including the whole object spectrum and providing preliminary labels. Ideally, this method would perform better than the random choice of objects. Secondly, since objects are classification units that entail further information than single pixels, we study the best method for characterising them. We consider the use of histograms, as an alternative to the common approach of considering the mean and standard deviation. Finally, this paper also considers a wide range of features (statistical, texture-based, geometrical and spatial) and analyses the best suited ones. The problem of feature selection in high spatial resolution imagery has been researched for urban-related environments (Herold, Liu, & Clarke, 2003), but there has not been much work in vegetation mapping (Yu, Gong, Clinton, Biging, Kelly & Schirokauer, 2006) (and more specifically, weed mapping), mainly because of the proximity of the spectral signatures for different species and the difficulties in capturing texture features in vegetation (Carleer & Wolff, 2004). We also try to validate the hypothesis that the same data features are useful for weed mapping considering different crops (sunflower and maize, which are broadleaved-dicotiledoneous and grass-monocotyledonous crops, respectively). Note that the base problem of this paper could be addressed using binary classification, however, crop detection is also an important challenge for a wide range of applications (such as plant counting, sowing failures detection or patch spraying positioning). Therefore, this problem is considered as a three-class task (weeds, crops and non-vegetation).

In this way, the experiments of this paper have three main purposes:

- To test whether the proposed method for object selection is useful to construct a reliable training set and to analyse the number of patterns needed to train the model.
- To test the use of histograms as opposed to the idea of using statistical metrics to simplify the objects.
- To ascertain which of the features considered are more useful for weed mapping in sunflower and maize crops via remote sensing imagery. To do so, a wide set of 40 features is selected and a procedure of feature selection is considered.

To conduct this study, different datasets have been created from sunflower and maize fields naturally infested by weeds and the results are validated by the use of the well-known SVM classifier.

The paper is organised as follows: Section 2 shows a description of the data acquisition process; Section 3 exposes the weed mapping system proposed in this work; Section 4 describes the experimental study, and Section 5 analyses the results obtained; Section 6 provides a discussion of the main findings; and finally, Section 7 outlines the conclusions and future work.

2. Data acquisition and processing

This section outlines the information concerning the data acquisition and image processing steps. The first subsection explains the characteristics of the UAV and the sensor considered, while the second one is focused on the image mosaicking process.

The UAV system was tested in a sunflower field situated at the private farm La Monclova (South of Spain), and in a maize field situated