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Research Paper

Two-stage procedure based on smoothed ensembles of neural networks applied to weed detection in orange groves

Joaquín Torres-Sospedra [a,*], *Patricio Nebot* [b]

[a] *Geospatial Technologies Research Group, Institute of New Imaging Technologies, Universitat Jaume I, Castellón, Spain*

[b] *Biofísica y Física Médica, Dpto. Fisiología, Facultat de Medicina i Odontología, Universitat de Valencia, Valencia, Spain*

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The potential impacts of herbicide utilization compel producers to use new methods of weed control. The problem of how to reduce the amount of herbicide and yet maintain crop production has stimulated many researchers to study selective herbicide application. The key of selective herbicide application is how to discriminate the weed areas efficiently. We introduce a procedure for weed detection in orange groves which consists of two different stages. In the first stage, the main features in an image of the grove are determined (Trees, Trunks, Soil and Sky). In the second, the weeds are detected only in those areas which were determined as *Soil* in the first stage. Due to the characteristics of weed detection (changing weather and light conditions), we introduce a new training procedure with noisy patterns for ensembles of neural networks. In the experiments, a comparison of the new noisy learning was successfully performed with a set of well-known classification problems from the machine learning repository published by the University of California, Irvine. This first comparison was performed to determine the general behavior and performance of the noisy ensembles. Then, the new noisy ensembles were applied to images from orange groves to determine where weeds are located using the proposed two-stage procedure. Main results of this contribution show that the proposed system is suitable for weed detection in orange, and similar, groves.

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1. Introduction

According to armers we interviewed, weed control is an expensive and time-consuming activity in agriculture. Moreover, long-term use of herbicides could damage people, animals and the environment. Unfortunately, agricultural herbicides and fertilizers have been uniformly sprayed in fields and overused in conventional practice. This has caused severe environmental pollution of high levels of Phosphate, Potassium or Nitrogen in groves and aquifers (Stayte & Vaughan, 2000). Therefore, efforts are being encouraged in designing weed-detecting technologies for precision spraying with selective herbicides in order to save herbicides and

* *Corresponding author*. Tel.: +34 964 38 7686.
E-mail addresses: Joaquin.Torres@uji.es (J. Torres-Sospedra), Patricio.Nebot@uv.es (P. Nebot).
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reduce environmental pollution without sacrificing crop yields (Bossu, Gee, & Truchetet, 2008; Burks, Shearer, Heath, & Donohue, 2005; Cho, Lee, & Jeong, 2002; Moshou, Vrindts, Ketelaere, Baerdemaeker, & Ramon, 2001). Our intention is to create a weed detection system and integrate it into an autonomous robotic system such as the *ATRV-2* we described in Nebot, Torres-Sospedra, and Martínez (2011).

The automatic detection of weed areas in orange groves has not been widely studied. However, there is a vast literature on weed/crop discrimination. In orange groves, there can be color similarities among weed areas and orange tree leaves so a direct detection based only on color can not be performed. Moreover, some important aspects such as weather or light conditions should be considered. For this reason, a two-stage system is introduced in this paper to detect weeds in groves where a robotic system can navigate through. This research is focused on orange groves due to its importance on the economy of western Spain. In the first stage, the main areas of a capture (e.g. *soil*) are determined. Later, in the second stage, weeds are detected on soil areas.

To perform the classification tasks we use ensembles of *Multilayer Feed-forward Networks* (also known as *MF net*, *Multilayer Perceptron* or *MLP network*). The performance of *MLP networks* can be improved by using a committee formed by several networks (see Bishop, 2006; Dietterich, 2000; Tumer & Ghosh, 1996). Using Artificial Neural Networks (ANNs) to detect weeds is not new. Moshou et al. (2001) and Sung, Kwak, and Lyou (2010) found that this network provided good classification rates for terrain classification and weed detection in different contexts. Moshou et al. (2001) used a *MLP network* for classification of reflectance spectra from crop and weeds using a spectrophotometer. Burks et al. (2005) used an *ANN* to distinguish among six species of weeds and detect their presence in raw images which covered approximately a ground area of 0.23 × 0.3 m. Cho et al. (2002) also used an *ANN* for weed-plant discrimination using images captured in zenital/overhead view. Cruz-Ramirez, Hervás-Martínez, Jurado-Expósito, and López-Granados (2012) also introduced an *ANN*-based model cover crop identification.

Other methods have also been used to perform weed detection. In Bossu et al. (2008) machine vision techniques were applied to discriminate between crops and weed using the captures of a monochrome CCD camera. Specifically, they applied image processing based on spatial information using a Gabor filter. Asif, Amir, Israr, and Faraz (2010) introduced a vision system for autonomous weed detection robot. This system enabled the navigation of the robotic system between the inter-row spaces of crop for automatic weed control but a direct weed detection was not introduced. Similar research was introduced in Tellaeche, Burgos-Artizzu, Pajares, and Ribeiro (2007) and Tellaeche, Pajares, Burgos-Artizzu, and Ribeiro (2011) where the weed detection consisted of two subprocesses: image segmentation and decision making with Support Vector Machines and Bayesian/Fuzzy k-Means Paradigms.

The main difference of the proposed system with respect to previous systems is that it relies on two ensembles of *MLP networks*, the first one for terrain-based classification and the second one for detecting weeds on soil. The weed detector is able to detect weeds on soil instead of discriminate crop and weeds. In this way, other elements such as leaves, fallen fruits and trash are automatically rejected. This system can be implemented into an autonomous computer-assisted robotic system, such as the ATRV-2. Finally, a new training algorithm with noise is applied to the two-stage system, due to promising preliminary tests we have previously obtained in other classification contexts.

2. Material and methods

The here proposed classification system for weed detection is divided into two stages. In the first one, the main elements of the image (orange grove) are determined. In the second one, weed detection is done on those parts of the image which corresponds to *Soil* according to the first classification (terrain classification) because weeds are located on soil. Both tasks are performed by means of an advanced classifier based on noisy ensembles of neural networks. A visual representation of the whole system is shown in Fig. 1.

This weed detector was designed to be integrated into an autonomous robotic system, specifically an *ATRV-2 vehicle*, whose vision system consists of a VGA camera (640 × 480 *pixels*). A manual calibration procedure, repeated in each grove, with visual marks was done. With this calibration, the distance (depth and lateral displacement) with respect to the robotic system was approximated. This approximation was accurate enough for close and medium-distance weed areas, even for a grove with semi-irregular ground (see Table 2).

In each stage, the corresponding features were extracted from the captured images and they were then processed by a classification system based on ensembles of neural networks generated with the *Noisy Learning* procedure.

This section is introduced as follows. First, the concepts related to the base classifier systems (neural networks) and ensembles are introduced. Second the new noisy learning is fully described. Then the general experiments for comparison purposes are detailed. Finally, the proposed two-stage system and the classifiers used in the two stages are fully described.

2.1. *General ensemble-based classification*

2.1.1. *Neural networks theoretical background*

The *MLP network* is the architecture used in the experiments carried out in this paper with ensembles. This is a feed-forward neural network with an architecture that closely resembles the α-Perceptron proposed by Rosenblatt in 1961 and the layered machine proposed by Nielson in 1965 as described in Pao (1989).

This network architecture was selected because it is widely known (see Bishop, 2006; Ripley, 1996) and has also been used for weed detection (Burks et al., 2005; Cho et al., 2002; Moshou et al., 2001). Moreover, the comparative studies carried out in Torres-Sospedra (2011) showed that this network could be used for weed classification and the computational costs were reasonable.

In this study, the original datasets were divided into three different subsets to perform the training and evaluation tasks.

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