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Active learning system for weed species recognition based on hyperspectral sensing

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Weeds have a devastating impact in crop production and yield in general. Current practice uses uniform application of herbicides leading to high costs and degradation of the environment and the field productivity. Site-specific treatments can be regarded as solutions either for reducing inputs or enable alternative non-chemical treatments. However, site-specific treatment needs accurate targeting through sensing. A new machine learning method is proposed, which discriminates between crop and weed species relying on their spectral reflectance differences. Spectral features were extracted from a hyperspectral imaging system that was mounted on a robotic platform. The proposed machine learning method suggests active learning by combining novelty detection and incremental class augmentation. Novelty detection was based on one-class classifiers constructed by neural networks. Best results for the active learning were obtained for the one-class MOG (mixture of Gaussians) and one-class SOM (self-organising map) classifiers when compared with one-class support vector machines and the auto-encoder network. The SOM and MOG performance in crop recognition was found to be 100% and 100% respectively. The recognition performance for different weed species varied between 31% and 98% (MOG) and 53%–94% (SOM).

1. Introduction

Environmental awareness and rising financial pressures are two of the major motivating forces behind precision farming. Weeds in production systems often appear in patches or as individuals between crop plants, but still they are managed similarly to the crop, large-scale and uniformly. Farmers indicate that weeds are one the most important threads in crop production (Gibson, Johnson, & Hillger, 2005). Herbicides are receiving negative attention, due to environmental issues from off-target movement and residues found on fruits and vegetables (Barbash, Thelin, Kolpin, & Gilliom, 2001; Tadeo, Sanchez-Brunete, Perez, & Fernandez, 2000). Combining control methods, chemical, mechanical and cultural, is the usual practice. Rarely are single weed plants targeted. In spite of

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Nomenclature

d	pre-specified threshold
$F(\lambda)$	class-to-class separation function
$K(x,z)$	Gaussian kernel of the SVM
M	denotes the SOM grid of units
R_{NIR}	near infrared reflectance in the 740–760 nm band
R_R	red reflectance in the 620–640 nm band
σ^2	standard deviation of Gaussian kernel
$\sigma^2{}_X(\lambda)$ and $\sigma^2{}_Y(\lambda)$	the standard deviations of the reflected light measurements at the same wavelength λ, both for classes X and Y.
x	new observation
x_k^{TARGET}	target vectors from samples belonging to the training set
x^{NEW}	new exemplar
$X(\lambda)$ and $Y(\lambda)$	the mean reflected light for class X values, respectively class Y at wavelength λ
z	centre of the Gaussian kernel

Abbreviations

API	Autonomous Platform Information System
ASM	Active Shape Modelling
BMU	Best Matching Unit
CCD	Charge Coupled Device
GLSM	Gray-Level Co-Occurrence Matrix
HSI	Hyperspectral Imaging System
LS-SVM	Least Squares Support Vector Machine
MOG	Mixture of Gaussians
NDVI	Normalised Difference Vegetation Index
PC	Principal Component
PCA	Principal Component Analysis
PGP	Prism Grating Prism
RGB	Red Green Blue
SOM	Self-Organising Map
SVM	Support Vector Machine

that, weeds similar to crop plants, are not yet handled at the individual plant scale. This has triggered some recent research (van Evert et al., 2011; Zijlstra et al., 2011). Aiming to decrease herbicide use; site individual targeted treatment is based on the precise detection of plants that are used as targets for spraying.

Sensors and machine learning algorithms are currently developed for cropping systems which may lead to real-time detection of target plants (e.g. weeds) hence enabling the targeted application of different management tools at fine spatiotemporal scales (Tellaeche, Pajares, Burgos-Artizzu, & Ribeiro, 2011). Sensor-based weed species recognition (Moshou, Ramon, & De Baerdemaeker, 2002) is considered as fundamental in order to apply the most appropriate chemical and dosage for spraying. Spectral leaf reflectance has been used in earlier research, trying to pinpoint differences between crops and weeds. In controlled laboratory conditions, it has been shown that it is feasible to tell apart crop plants from weeds with high confidence, as well as between various weeds by using the spectral reflectance of the leaves (Borregaard, Nielsen, Norgaard, & Have, 2000). A few approaches for weed recognition have been proposed in the literature. Some methods are based on leaf size and shape analysis. Søgaard (2005) presented a method for automated machine vision based classification of weed species by using the algorithm of ASM (active shape modelling) which resulted in successful classification of weed species with an accuracy rate between 65% and 90%. The computational requirements prohibit the online application foreseen in this study due to heavy image processing. Other similar research has shown that the difference in spectral reflectance characteristics of plant species may be enough in order to discriminate between them. Discrimination of maize crops from weeds was presented in Moshou, Vrindts, De Ketelaere, De Baerdemaeker, and Ramon (2001). The obtained results gave a correct classification of 96% for the maize and 90% for the weeds. In the case of sugar-beet weed discrimination from weeds, the successful recognition was 98% for the sugar-beets and 97% for the weeds. However, these results concerned crop-weed classification and not recognition between weed classes. In the presented work, hyperspectral sensing has been utilised to enable the classification of crops and weeds relying on neural network and statistical algorithms.

Wang, Zho, and Palm (2008) used a portable spectroradiometer together with airborne hyperspectral imagery for mapping an invasive weed (*Sericea lespedeza*) in order to quantify its invasiveness in pastures in Mid-Missouri, USA. During processing, a first order derivative analysis was applied for calculating derivatives the maximum spectral difference between *Sericea* and *Fescue*, which was the dominant grass species in the pastures. This method could estimate the volume of S. *lespedeza* with an error of 11%. Another attempt to identify weed species from hyperspectral images was proposed by Moshou et al. (2002). In this work, a neural network, the self-organising map (SOM) was extended with local linear models in order to increase classification performance compared to other more commonly used neural classifiers. This method achieved classification results between 52% and 99% in different weed species. This approach was based on supervised classification and several classifiers were compared with the proposed architecture which was an improved variant of SOM with local linear modelling.

The problem of classification of different weed species is quite complex due to the time of appearance in a field which is not known in advance or is due to which species will emerge. The proposed concept in this work concentrates on the idea that these appearances can be treated as changes in expected sensor signatures. The expected sensor signatures could be those of crop plants which are well known in advance. Any deviations from expected spectra can be treated and categorised using novelty detection techniques. A manner to implement novelty detection is based on one-class classifiers. One-class classifiers work by learning a baseline condition when trained or calibrated by being shown normally occurring data examples. Thus, data examples which do not belong to the training baseline set of crop plants are most likely to be a member of an invasive species like weeds.

Novelty detection can be creatively combined with a variety of machine learning techniques in order to detect

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