BIOSYSTEMS ENGINEERING 166 (2018) 28–43

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

On-line crop/weed discrimination through the Mahalanobis distance from images in maize fields

Iván D. García-Santillán [a,b,*], Gonzalo Pajares [a]

[a] Department of Software Engineering and Artificial Intelligence, Faculty of Informatics, Complutense University, Madrid, Spain

[b] Department of Software Engineering, Universidad Técnica del Norte, Ibarra, Ecuador

ARTICLE INFO

Article history:
Received 20 July 2017
Received in revised form
25 September 2017
Accepted 8 November 2017

Keywords:
Crop/weed discrimination
Mahalanobis distance
Image segmentation
Machine vision

This study proposes a new automatic method for crop/weed discrimination in images captured in maize fields during the initial growth stages. The images were obtained under perspective projection with a camera installed on board at the front part of a tractor. Different approaches have addressed the problem based on crop row determination and then assuming that inter-row plants are weeds. Nevertheless, an important challenge is the identification of weeds intermixed within the crop rows. This issue is addressed on this paper by applying a minimum criterion distance based on the Mahalanobis distance derived from a Bayesian classification approach, this makes the main contribution. The identification of both intra- and inter-row weeds is useful for more accurate weed quantification for site-specific treatments. Image quality is affected by uncontrolled lighting conditions in outdoor agricultural environments. Also, different plant densities appear due to different growth stages affecting the crop/weed identification process. The proposed method was designed to deal with the above undesired situations, consisting of three phases: (i) segmentation, (ii) training and (iii) testing. The three phases are executed on-line for each image, where training is specific of each single image, requiring no prior training, as it is usual in common machine learning-based approaches, mainly supervised. This makes the second research contribution. The performance of the proposed approach was quantitatively compared against three existing strategies, achieving an accuracy of 91.8%, pixel-wise determined against ground-truth images manually built, with processing times ≤280 ms, which can be useful for real-time applications.

1. Introduction

1.1. Problem statement

Machine vision systems applied to agricultural tasks have great potential, as explained in Brosnan and Sun (2002) and Davies (2009). The use of technology, including machine vision systems, in agricultural applications can reduce manual tasks and the cost of crop production (Barreda, Ruíz, & Ribeiro, 2009), and can contribute to the productivity and competitiveness of farmers to ensure agricultural supplies. Moreover, the use of traditional farming methods sometimes

* Corresponding author. Department of Software Engineering and Artificial Intelligence, Faculty of Informatics, Complutense University, Madrid, Spain.
E-mail addresses: idgarcia@utn.edu.ec (I.D. García-Santillán), pajares@ucm.es (G. Pajares).
https://doi.org/10.1016/j.biosystemseng.2017.11.003

Nomenclature

Abbreviations

AES	algorithm based on thresholding and morphological operations
CIVE	colour index of vegetation extraction
COM	Combination of green indices
ExG	excess green
ExR	excess red
ExGR	excess green minus excess red index
LPG	liquefied petroleum gas
LVQ	algorithm based on learning vector quantisation
NDI	normalised difference index
ODMD	on-line discrimination by Mahalanobis distance
RHEA	robotics and associated high-technologies and equipment for agriculture and forestry
ROI	region of interest
SVM	algorithm based on support vector machine
VEG	vegetative index

Symbols

a, b, d	coefficients for the quadratic polynomial
c	pixels belonging to crop class
$\overline{C}$	3-dimensional vector containing $\overline{R}_c, \overline{G}_c, \overline{B}_c$
D_M^2	Mahalanobis distance squared
D_c	Mahalanobis distances for crop class
D_w	Mahalanobis distances for weed class
$Height_{(ROI)}$	height of the ROI in pixels
k	Kappa coefficient
l	length in pixels
$L1$, $L2$, $L3$, $L4$	crop rows labelled from left to right
m, e	slope and intercept of the straight line respectively
n	number of pixels of the class
$Margin_{(base)}$	width in pixels at the base of the ROI
$Margin_{(top)}$	width in pixels at the top of the ROI
R, G, B	RGB (red, green and blue) spectral channels
$\overline{R}, \overline{G}, \overline{B}$	average for each spectral component R, G, B
$\overline{R}_c, \overline{G}_c, \overline{B}_c$	$\overline{R}, \overline{G}, \overline{B}$ pixels representing the crop class
$\overline{R}_w, \overline{G}_w, \overline{B}_w$	$\overline{R}, \overline{G}, \overline{B}$ pixels representing the inter-row weed class
$\boldsymbol{\mu}$	vector (centroid) containing $\overline{R}, \overline{G}, \overline{B}$
w	pixels belonging to weed class
$\overline{W}$	3-dimensional vector containing $\overline{R}_w, \overline{G}_w, \overline{B}_w$
x, y	independent and dependent variables of the straight line, respectively
(X, Y)	pair of variables of the spectral components (R, G, B)
$\overline{X}, \overline{Y}$	pair of variables of the average spectral components $(\overline{R}, \overline{G}, \overline{B})$
$\mathbf{z}$	3-dimensional vector containing R, G, B spectral components

may lead to indiscriminate use of chemicals (herbicides, fertilisers), increasing production costs, soil depletion and environmental pollution (Astrand & Baerveldt, 2005; Kataoka, Kaneko, Okamoto, & Hata, 2003).

Process automation is gaining an important relevance today. In this regard, crop/weed discrimination based on images has currently received special dedication in precision agriculture. Indeed, plants located inside the inter-row spaces can be considered with very high probability to be weeds, requiring site-specific treatments (Emmi, Gonzalez-de-Soto, Pajares, & Gonzalez-de-Santos, 2014; RHEA, 2014). The intra-row weed identification is important too. However, this task is complex because crops and weeds located in the intra-crop row space are intermixed and overlapped, with a high degree of similarity in their spectral signatures.

Image quality is affected by uncontrolled lighting conditions (sudden shadows, excessive or poor illumination) in outdoor agricultural environments. Also, different plant heights and volumes due to growth stages affect the crop/weed identification process. Several solutions have been proposed to cope with the above adverse situations with the aim of discriminating between crops and weeds (Ahmed, Al-Mamun, Bari, Hossain, & Kwan, 2012; Guerrero, Pajares, Montalvo, Romeo, & Guijarro, 2012; Montalvo et al., 2012b; Tellaeche, Pajares, Burgos-Artizzu, & Ribeiro, 2011). However, because of the intrinsic difficulty involved in outdoor agricultural environments, an extra research effort is still required; mainly to discriminate crops and weeds without requiring an off-line exhaustive training process as occurs with supervised learning-based techniques. In addition, it must be considered that an additional benefit of an on-line trained system is that it can adapt to local variations in the field, minimising the local vulnerability produced by global and off-line training system (Midtiby, 2012, p. 88).

According to the above considerations, a new strategy based on a machine vision system was designed for crop/weed discrimination in wide row crops (maize fields) at initial growth stages (up to 40 days), focused on weeds intermixed with crops in the intra-row space, by applying a minimum criterion distance based on the Mahalanobis distance derived from a Bayesian classification approach. This makes the main contribution. The method proposed was designed to deal with the above mentioned adverse environmental conditions focusing on its performance in terms of accuracy and efficiency, measured through the corresponding analysis of the confusion matrix and the Kappa coefficient.

The image processing consists of three phases, which are executed on-line for each image, where the classical training required by the Bayesian classifier is applied exclusively on each single image, requiring no prior training with a set of selected images. This makes the second research contribution. In addition, the method identifies separately weeds located on the inter- and intra-row spaces in both curved and straight crop rows (García-Santillán, Guerrero, Montalvo, & Pajares, 2017a, b).

The idea comes from the RHEA (2014) project, in which one of the tractors in the fleet was dedicated to apply site-specific treatments on maize fields, where the detection of weed pressure was an essential objective. This tractor was equipped with an automatic mechanical/thermal tool, based on