BIOSYSTEMS ENGINEERING 157 (2017) 1–12

Available online at www.sciencedirect.com

ScienceDirect

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

Research Paper

Weed segmentation using texture features extracted from wavelet sub-images

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ARTICLE INFO

Article history:
Received 30 December 2015
Received in revised form
16 November 2016
Accepted 8 February 2017

Keywords:
Artificial neural networks
Sugar beet
Wavelet sub-band
Weed detection

Weed detection is a complicated problem which needs several sources of information to be gathered for successful discrimination. In this paper wavelet texture features were examined to verify their potential in weed detection in a sugar beet crop. Successive steps in a discrimination algorithm were designed to determine the wavelet texture features for each image sub-division to be fed to an artificial neural network. Co-occurrence texture features were determined for each multi-resolution image produced by single-level wavelet transform. Image segmentation was based on the decision made by neural network to label each sub-division as weed or main crop. Optimisation of the algorithm was tried by investigating two manners of discrimination of weeds from the main crop. Principal Component Analysis was used to select 14 from the 52 extracted texture features. Results demonstrated that the wavelet texture features were able to effectively discriminate weeds among the crops even when there was significant amount of occlusion and leaves overlapping.

1. Introduction

Sugar beet (*Beta vulgaris* L.) is one of the most important industrial plants in the world. It supplies about a quarter of the world's sugar demand (Draycott, 2006). Sugarbeet ranks eighth in global food and agricultural commodities production with about 270 million tons in 2012 (FAOSTAT, 2015). Precursors of the modern sugarbeet have their origins in Asia, where the crop is usually grown under rainfed conditions. Iran was 14th in the world ranking of sugarbeet producers in 2013 with a production volume of about 4.185 million tons (Statista, 2015).

The presence of weeds in sugarbeet fields results in reduction in yield quality and quantity as the weeds compete with the main crop for space, light, moisture and nutrients. The losses are higher at early vegetative stages. Weeds are also a threat to cultivation and harvest operations (Hembree & Norris, 2005). Hence, early removal of weeds is necessary to minimise crop losses. Effective weed control in sugar beet cultivation is a very important and difficult agricultural operation since sugar beet is a slow growing crop and very sensitive to weed competition before the six to eight leaves stage (Scott, Wilcockson, & Moisey, 1979).

Various types of herbicide with high performance are available for weed control in sugar beet fields but there are some constraints with chemical weed removal such as the high cost of herbicides and negative effects on environment and human health (Kughur, 2012).

Mechanical implements have been largely used for weed control in sugar beet fields. Inter-row cultivators are the most common machine used for mechanical weed control (Ahmad & Taufik, 2012). Due to the proximity of intra-row weeds to the

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http://dx.doi.org/10.1016/j.biosystemseng.2017.02.002

Nomenclature

ANN	Artificial Neural Networks
$C(i,j)$	(i,j)th entry in GLCM
$C_x(i)$	sum of the entries in the ith row of GLCM
$C_y(j)$	sum of the entries in the jth column of GLCM
μ_x	average of C_x
μ_y	average of C_y
σ_x	standard deviation of C_x
σ_y	standard deviation of C_y
Cl_{sh}	Cluster shade
Cl_{pr}	Custer prominence
Corr	correlation texture feature
CSR	Correct segmentation rate
D_{ent}	entropy of difference
D_{var}	variance of difference
Enr	energy texture feature
Ent	Entropy texture feature
GLCM	Gray Level Co-occurrence Matrix
HH	High–High wavelet decomposition sub-band
HL	High–Low wavelet decomposition sub-band
IDM	Inverse Different Moment
Iner	Inertia texture feature
L	Luminance
LH	Low-High wavelet decomposition sub-band
LL	Low–Low wavelet decomposition sub-band
M	Green − red colour index
R^2	Coefficient of determination
RMSE	Root Mean Squared Error
S_{ave}	Sum average of co-occurrence matrix
S_{ent}	Sum entropy of co-occurrence matrix
S_{var}	Sum variance of co-occurrence matrix
Var	Variance texture feature

crop or seed lines, it is more difficult to eliminate (Pérez-Ruiz, Slaughter, Gliever, & Upadhyaya, 2012). Hand hoeing of intra-row weed removal is a common practice in sugar beet fields (Kaya & Buzluk, 2006) which is very effective but time consuming, labourious and expensive.

Considering the above restrictions, it is needed to seek better solutions for effective and selective intra-row weed management procedure. The key for selective weeding is to discriminate weed from crop.

In recent years, along with advances in computer-based systems, several approaches of using image processing for weed detection have been investigated (Agın & Taner, 2015; Burks, Shearer, & Payne, 2000; Cho, Lee, & Jeong, 2002; Kumar & Prema, 2016; Lavania & Matey, 2015; Peng & Jun, 2011; Prema & Murugan, 2016; Schuster, Nordmeyer, & Rath, 2007; Wang, Wilkerson, Gold, & Coble, 2001; Xavier, Ribeiro, Guijarro, & Pajares, 2011).

Montalvo, Guijarro, Guerrero, and Ribeiro (2016) successfully segmented maize crop from weeds using combinations of RGB colour components derived from Principal Component Analysis (PCA). However, when the colour difference between plants and weeds is not significant, inevitably other methods are needed. Tang, Chen, Miao, and Wang (2016) developed a weed detection algorithm for corn fields. They used thresholding on Cb component in YCrCb colour space to segment green objects. The centre line of the crop rows in the segmented images were identified using a method that combined vertical projection images with linear scans. Images were divided into grids and the weed infestation inside the grids was calculated by the horizontal scanning. They reported 92.5% accuracy of their algorithm in their tests. The algorithm detecting accuracy wasn't evaluated for conditions of heavy weed cover densities.

Texture analysis is one of the most widely used image processing techniques to extract information from images. Image texture is a conceptual description determined by spatial variation in pixel values in an image (Chen, Pau, & Wang, 1998) to explain some properties of a region such as coarseness, smoothness, and regularity (Gonzalez & Woods, 2002). Texture based image processing have been investigated in several agricultural experiments (Samal, Brandl, & Zhang, 2006; Wooten, Filip-To, Igathinathane, & Pordesimo, 2011; Zhai, Thomasson, Boggess, & Sui, 2006; Zhang, Wang, Ji, & Phillips, 2014). Statistical texture analysis has been used for discrimination between crop and weeds (Agrawal, Singh, Bora, & Lin, 2012; Dryden, Scarr, & Taylor, 2003; Ma, Zhu, Liu, Xiong, & Chen, 2013).

Wavelet transformation of digital images extracts information from several spatial orientations helpful for analysing the content of images, texture discrimination, and fractal analysis (Mallat, 1989). A 2D wavelet transform can be applied to characterise, compare and separate the object surface texture in images (Lee & Pun, 2000). Guijarro, Riomoros, Pajares, and Zitinski (2015) proposed a strategy based on discrete wavelet transform combined with colour segmentation for improving soil-greenness detection accuracy in agricultural images. Their results revealed that the use of wavelet transform increased the segmentation performance in their images of barley and corn fields by 4.5% compared to existing colour based methods. There are also several studies on applications of wavelet transform techniques for crop-weed discrimination (Bossu, Gée, Jones, & Truchetet, 2009; Chou, Chen, & Yeh, 2007; Ishak, Hussain, & Mustafa, 2009; Kavdır, 2004). In most of the studies conducted on the use of wavelet transform for weed detection, the goal has been plant classification. Although plant classification by means of texture analysis has been studied in some of the previous research, few studies have been conducted on application of wavelet textures for segmentation of areas where both plant and weed grow very closely together.

In this research we considered the combination of wavelet features in a neural network to provide a texture based discriminator to segment the weeds from the main crop. Such a segmentation operation calls the integration of several image processing approaches. Therefore the objectives of this research were:

1. To assess the capability of wavelet texture features for discrimination of four common weed species in sugarbeet at early stages of growth.
2. To determine the optimum specification of the algorithm including the most influent wavelet texture features, and selected neural network for discrimination of four common weed types in sugarbeet.