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Research Paper

Plant leaf detection using modified active shape models

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ARTICLE INFO

Article history:
Received 9 October 2012
Received in revised form
29 April 2013
Accepted 7 June 2013
Published online 14 July 2013

We propose an *in situ* detection method of multiple leaves with overlapping and occlusion in greenhouse conditions. Initially a multilayer perceptron (MLP) is used to classify partial boundary images of pepper leaves. After the partial leaf boundary detection, active shape models (ASMs) are subsequently built to employ the images of entire leaves based on *a priori* knowledge using landmark. Two deformable models were developed with pepper leaves: Boundary-ASM and MLP-ASM. Matching processes are carried out by deforming the trained leaf models to fit real leaf images collected in the greenhouse. MLP-ASM detected 76.7 and 87.8% of overlapping and occluded pepper leaves respectively, while Boundary-ASM showed detection rates of 63.4 and 76.7%. The detection rates by the conventional ASM were 23.3 and 29.3%. The leaf models trained with pepper leaves were further tested with leaves of paprika, in the same family but with more complex shapes (e.g., holes and rolling). Although the overall detection rates were somewhat lower than those for pepper, the rates for the occluded and overlapping leaves of paprika were still higher with MLP-ASM (ranging from 60.4 to 76.7%) and Boundary-ASM (ranging from 50.5 to 63.3%) than using the conventional active shape model (from 21.6 to 30.0%). The modified active shape models with the boundary classifier could be an efficient means for detecting multiple leaves in field conditions.

1. Introduction

In conventional farming, agricultural cultivation and pest management are conducted manually by farmers, causing human health problems and productivity loss. Recently, precision agriculture has been proposed to reduce the chemical stress to humans and agricultural products, relying on new technologies (Zhang, Wang, & Wang, 2002), such as computer vision and robotics.

Proper judgement of leaf status is essential for effective management of crops including cultivation and crop protection. Automatic detection of individual leaves is a fundamental

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http://dx.doi.org/10.1016/j.biosystemseng.2013.06.003

Nomenclature

ASM	Active shape model
b	Vector of weights
CPU	Central processing unit
D_m	Mahalanobis distance
G_{rgb}	Gray level value
kNN	k-nearest neighbour
l	Length from leaf centroid to boundary
MLP	Multilayer perceptron
n	Number of landmark points
N	Number of training images
p	Control point of Bezier curve
p_c	Centroid of leaf
P	Matrix of first t eigenvectors
PC	Personal computer
RAM	Random access memory
RGB	Red, Green and Blue
ROC	Receiver operating characteristic
S_m	Covariance matrix of pixels
t	Number of eigenvectors
T	Transpose operator
$\overline{X}$	Mean shape
x_i	ith shape in the training set
$x_{i,j}$,	x coordinate of jth point in ith training shape
x_{rgb}	Pixel in the RGB space
$y_{i,j}$	y coordinate of jth point in ith training shape
α	Angle at control point p_1
β	Angle between leaf centroid and boundary
μ_m	Mean value of vegetation pixels

task for achieving precision in agricultural practices, such as micro-spray, de-leafing, and plant inspection. Leaf detection is also a crucial and challenging task for vision-guided agricultural robotics, for instance, in a weed control robot for automatic weed recognition and precision control (Slaughter, Giles, & Downey, 2008).

Plant leaves, however, contain complex information (e.g., colour, morphology, and texture) which vary with growth conditions and are consequently difficult to detect or identify. Since the 1980s, numerous studies on leaf segmentation have been conducted (Guyer et al., 1984), including recent development of genetic and watershed algorithms for leaf information extraction (Lee & Slaughter, 2004; Neto, Meyer, & Jones, 2006; Tang, Zhao, & Tao, 2009; Wang, Ding, & Fang, 2008; Wang, Huang, Du, Xu, & Heutte, 2008). In addition, spectral images and stereo vision techniques have been introduced to solve problems of leaf extraction and segmentation of overlapping leaves (Noble & Brown, 2008; Teng, Kuo, & Chen, 2011). However, the early methods were largely dependent on local image features since only partial information is usually available under complex field conditions (e.g., overlapping leaves and leaves hidden from cameras). Considering both the importance and difficulty in obtaining information from whole leaf images, global information processing at higher level image recognition should also be developed to detect entire leaves.

Integrated algorithms could be a candidate for combining partial images to produce global image processing. The accumulation of *a priori* knowledge about targets (leaves) would be an alternative to generation of global information. Manh, Rabatel, Assemat, and Aldon (2001) developed a deformable template to accumulate information on weed leaves on the basis of the tips of leaves, while De Meezo, Rabatel, and Fiorio (2003) reported another shape-guided approach for leaf segmentation. Recently, Active Shape Models (ASMs) have been introduced for identification and classification of weed species (Søgaard, 2005; Persson & Åstrand, 2008; Swain et al., 2011). An ASM is a deformable template model and has sufficient tolerance to match shape variations of the same objects using *a priori* knowledge, and is sufficiently robust to locate known objects in the presence of noise and occlusion (Cootes & Taylor, 1992; Cootes, Taylor, Cooper, & Graham, 1995). ASM has been effectively used in various fields including medical image analysis, face recognition, and leaf pose estimation (Hamarneh, Abugharbieh, & McInerney, 2004; Milborrow & Nicolls, 2008; Moeslund, Aagaard, & Lerch, 2005).

Previous studies on leaf detection, however, were mainly concerned with identification of individual leaves with simple shapes such as weed leaves (e.g., smooth boundaries, linear shape). In this study, modified ASMs were developed to detect more complex shapes of vegetable leaves such as pepper leaves. By using the deformable process of ASM, two schemes are proposed: 1) Boundary-ASM matching leaf boundaries in binary images, and 2) MLP-ASM combining ASM with Multilayer Perceptron (MLP) classifier in gray-scale images. In order to effectively match whole leaves using ASM, leaf boundaries were identified prior to the execution of ASM for detecting whole leaves. An artificial neural network, MLP, was utilised as a boundary classifier.

An overview of the leaf detection procedure is shown in Fig. 1. After background removal, image edges representing leaf boundaries and veins were segmented according to the Bezier curve fitting. MLP was subsequently utilised for identification of leaf boundaries on the basis of input data given by

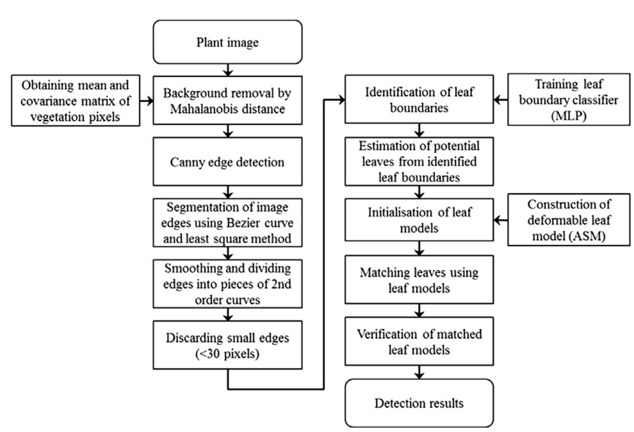

Fig. 1 – Overall procedure of learning and recognition of multiple leaves based on the deformable model and the boundary classifier.