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A new recognition of crop row based on its structural parameter model

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Abstract: The recognition of crop rows under complex field conditions is essential for vision-based guidance systems of an agricultural robot. This paper reports the development of an intelligent recognition algorithm of crop row structure. This algorithm consists of four core parts: 1) a sector-scan for extracting potential crop row lines along a horizontal line across the crop row (defined as the base line, BL) for reducing required computation time; 2) a structural parameter model for obtaining structural information about irregular crop rows with complicated field backgrounds; 3) a crop row density model for searching the candidate crop rows; 4) a logistic regression for selecting the second crop row nearest to the reference row to determine the inter-row spacing. To minimize the computation time, green vegetation feature extraction is used to preprocess field images, and a statistical filter is also used to filter out isolated or small patch noises induced by residuals, stones, shadows, and weeds in those images. The developed algorithm has been tested in fields of different crops of maize, wheat, rape, and strawberry, with some of the testing fields being purposely selected to include large amounts of weeds, different soil backgrounds, or large non-crop regions. Experimental results verify that the developed algorithm can achieve a 97.7% recognition rate for a reference row and a 94.3% recognition rate for the second crop row. The mean of angle error is 0.06 rad with the standard deviation 0.06s. Although the average computation time from acquiring the image to obtaining the guidance parameters is 6.0 s, those results indicate that the developed algorithm can effectively, accurately and robustly get the needed guidance information even under the complicated field conditions for guiding low-speed agricultural equipment operating in different crop fields.

Keywords: Sector scan; Structural parameter model of crop; Density model of row; Modelling and Identification; Robotics and Mechatronics for Agricultural Automation

1. INTRODUCTION

The development of electronics, computer, automation and artificial intelligence has made autonomous guidance of agricultural equipment practically feasible. The ability to use it in a wide range of field operations such as spraying weeding, harvesting and tilling, autonomous guidance could help to reduce operator fatigue and improve operation efficiency and safety in those operations (Reid, et al., 2000; Han, et al., 2004;Mousazadeh, 2013). The availability of low-cost cameras and the advancement of computer vision techniques made vision-based guidance an attractive technology for agricultural applications. In the last two decades, a few guidance technologies based on machine vision technologies have been developed for different applications (Li, et al., 2009; Mousazadeh, 2013). There have been many algorithms developed for detecting crop rows based on its characteristics by using image processing techniques (Jiang, 2015). Firstly, since Hough transform (HT) was proposed in the 1960's, in the agricultural engineering field, HT and some variations on Hough's original transform have been extensively used for crop row detection in vision-based agricultural navigation systems (Gée et al., 2008; Bakker et al., 2008;Jiang et al., 2015). In order to speed up the calculation, Xu, et al. (1990) proposed a randomized Hough Transform (RHT) algorithm. However, the method is not feasible in extracting crop row lines when meeting complicated backgrounds with weed patches, missing row, and serious irregularity of row growth (Jiang, 2015), because it lacks the proper structure of crop rows, only considering crop plants (Ji et al., 2011). Then, since the crop row aligns in the field, it is easy to use the fitting method to extract a row line. For example, Montalvo et al. (2012) proposed a crop row detection method in maize fields with a high number of weeds present. The strategy applied double of Otsu's method to separate weeds and crops, then the least squares fitting was used to extract crop row lines. Thirdly, the vanishing point from the crop image can be regarded as a feature of crop row detection. In this instance, Gée et al. (2008) constructed the vanishing model of the crop row in perspective, and then used the double Hough transform to detect the crop row. Fourthly, the horizontal strips of a crop row image can be used to detect a crop row. Typically, Sainz-Costa et al. (2011) proposed an algorithm based on the analysis of video sequences to detect crop rows, in which they used the horizontal strips and vertical computation of gray values. Besides, stereovision has been used successfully to detect crop rows. For instance, Kise et al. (2005, 2008) utilized stereo vision system to detect crop rows of field terrain. Wang et al. (2011) developed a stereo image-processing algorithm to detect and track ground features to calculate the lateral offset of the agricultural robot. In recent years, some optimal complex algorithms have been proposed to recognize a crop row. For example, Vidovic and Scitovski (2014) proposed a new efficient method for line detection based on known incremental methods of searching for an approximate globally-optimal partition of a set of data points. Jiang et al. (2015) presented a new automatic and robust crop rows

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detection algorithm for a vision-based agricultural machinery guidance system. The core concept is that the utilization of the natural property of the crop row consisting of many regions of interest (ROI) in the binary image. The existing algorithms are mostly based on crop row detection. Few studies have focused on structural information of the crop rows by comparison. This research presents a new recognition of crop rows based on the structural parameter model of crop rows.

As many field crops are cultivated in the form of row, the crop rows can provide useful geometrical properties for guiding agricultural equipment performing various operations. There are a few vision-based crop row detection algorithms developed for different applications. However there is still a need to improve their performance to make them more robustly and accurately detect crop rows, especially when crop is growing unevenly, even there are missing rows, or the soil is covered by weed patches. For example, when there is only one row recognized, it would be difficult for the automatically-guided agricultural equipment to work properly in the field. Aimed at improving the robustness in accurately detecting crop rows under actual field conditions, this study focuses on developing a new crop row recognition method. The method is based on its structural information for obtaining sufficient vision-based navigation information for agricultural equipment operating in fields with missing crops in rows, soil covered by weed patches, or crops growing unevenly.

2. Materials and methods

For recognizing crop rows, the different crops images were acquired under field conditions, and are pre-processed to remove some of the noises and disturbances by using a filter designed in this paper. A sector-scan method is proposed to extract potential crop rows; and then the reference row is determined according to the maximum density of the row. For accurately detecting the desired row lines under complicated soil backgrounds conditions, we construct a parameter model of crop rows based on the logical relation of the structural information of crop rows by using a vanishing point position. Then, the neighboring rows are searched based on the density model of row. Finally, we can recognize the second row by employing Logistic Regression. And 60% of the images in images sets A, B, C, D and E are utilized to train the logistic regression model. The remaining 40% are used to test the algorithm proposed in this paper. At the same time, we invite several experienced farming experts to visually decide whether a row line detected is correct.

2.1 Image acquisition

Image sequences are acquired for various crops at different locations and named as image sets A, B, C, D and E based on the crop and location shown in Table 1. The aperture is fixed using the video manual mode of the camera in the experiments. The soil backgrounds and growth state of the rape, wheat, maize and strawberry plants are typically those representative of most situations that agricultural equipment may encounter in young crop fields. The images consist of various conditions such as different row spacing, various soil backgrounds, uneven distribution of crop plants on the same row, and uneven growth of a crop row. Additionally, some disturbances such as a greenhouse, trees, sky, or buildings in an image also can cause detecting difficulties. All images in the image sets are taken under good lighting conditions and can preserve enough information about the crop row structure for use with a vision guidance system for agricultural equipment. The image data in this paper were all processed on a notebook computer, a Lenovo ThinkPad with the following specifications: Intel® Core™ i5-3210M; CPU: 2.5 GHz; RAM: 4.00 GB; 64-bit operating system. The full recognition program is developed using the Matlab7.6 tool.

Table 1 Image sets A, B, C, D and E based on the crop and location

Image set	Crop	Time	Location	Resolution	Image number	Camera type	Camera height	View angle	Focal length
A	celery/ kale	Summer of 2007	Test field of SCAU	656*494	18	A301fc	73 cm	30～45	12 mm
B	wheat	Morning of 3/10/20 13	Test field in Northern China	720*480	17	Q8N04C	100 cm	20～35	28 mm
C	maize	Afterno on of 6/22/20 13	Test field of IMU	656*494	81	MV-VD030S C	130 cm	30	8 mm
D	maize	Afterno on of 6/4/2011	Test field of IMU	656*494	18	MV-VD030S C	100 cm	30	8 mm
E	strawb erry	Afterno on of 10/17/2 015	Test greenhouse of IMU	640*480	218	BB2-03S2C-60	50~150c m	15~45	6mm

2.2 Sector-scan method

In existing algorithms, most of the crop row lines recognition are only restricted to recognizing isolated crop rows, and cannot be applied to the structural information of crop rows under complicated field environments. Actually, as we