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Crop-row detection algorithm based on Random Hough Transformation

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ABSTRACT

It is important to detect crop rows accurately for field navigation. In order to spray on line, a variable rate spray system should detect the crop center line accurately. Most existing detection algorithms are slow to detect crop rows because of the complicated calculation. The gradient-based Random Hough Transform algorithm could improve the calculation speed and reduce the computation effectively by the more-to-one merger mapping method. In order to detect the center of the crop row rapidly and effectively, the detection algorithm with gradient-based Random Hough Transform was proposed to detect the center line of crop rows. We tested the center line of crop-row detection for three kinds of plant distribution, being sparse, general and intensive. The experimental results showed that the detection algorithm with gradient-based Random Hough Transform was adaptive to the difference of plant density in the crop row effectively. Contrasted with the detection algorithm based on the Hough transform, the detection algorithm based on the gradient-based Random Hough was faster and had a high detection correction rate.

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0. Introduction

Variable rate spray systems based on machine vision are important to reduce the amount of chemical pesticide and protect the environment. Research for real-time and environmentally adaptive plant locations is crucial to a variable rate spray system. The center line of the crop row should be detected to ensure spraying on-row and for vehicle navigation. The center line of the crop row is mainly detected by an algorithm based on the Hough transform [1–5] or projection [6–9]. The Hough transform algorithm is used widely in line detection for its high robustness. The Hough transform was first proposed by Marchant et al. [1] to detect the crop center line. The experimental results showed the crop center line could be detected effectively by the Hough transform. The crop navigation baseline detection algorithm was proposed to combine the Hough transform with mass analysis [3]. The algorithm was tested and verified in the soybean field. The experimental result indicated that the algorithm could overcome the impact of shadows. The adaptive Hough transform algorithm was proposed to detect ripe lettuce rows [4]. Experiments showed that the algorithm was efficient for the shadows and irregular noise. However, this algorithm could not extract the crop row line correctly when there were gaps in the crop row. The crop row line detection algorithm based on projection [7] was put forward. The field crop image was segmented into several equal parts first, and then projected in the vertical direction to calculate the barycenters of the crop in every part. The barycenters were connected with a linear regression method, and then the crop center line was obtained. A method based on vertical projection was described [8]. Firstly, the row crop and background were segmented by the excess green value. Secondly, the image trips were divided by the crop image horizontally and the position was calculated by detecting the peak on the curve resulting from vertical projection of the trips. Finally, the crop rows center lines were established by robust regression. The experimental results of soybean images confirmed the effectiveness of this method.

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The Hough transform algorithm operation was slower for the huge computation. The Hough transform has seldom been applied in a real-time system. The randomized Hough transform algorithm effectively reduced the computation by using technologies such as: random sampling, convergence mapping, dynamic link lists and so on. The algorithm operation speed became faster [10]. In order to detect the crop row centerline quickly and effectively, a randomized Hough transform algorithm based on a gradient was proposed to detect the center line of the crop row in this paper. It was discussed for detecting the center line of the crop row in which plant density was different.

1. Random Hough transform

The Hough transform is a line detection algorithm based on the point to line duality principle. The basic idea of the Hough transform algorithm is to map a set of points in image space to a set of lines in parameter space. The points in image space are all located on the line ($y = kx + b$), while the mapped lines in parameter space pass the common point (k, b). The algorithm changes line detection in image space to point detection in parameter space. The Hough transform algorithm needs huge computation with excessive redundancy. At the same time the quantization precision of parameter space also affects the detection accuracy. The Hough transform algorithm is limited in application to real-time systems.

Because of the shortcoming of the Hough transform algorithm, Xu and Oja [10] proposed a randomized Hough transform algorithm (RHT). The RHT overcomes the deficiencies of Hough transform algorithm fundamentally. The basic idea of the RHT is described as following. Two points are selected randomly in the image space (XY). Then only one point (k, b) is identified in parameter space (KB) by the equation as follows.

$$\begin{cases} k = \dfrac{y_1 - y_2}{x_1 - x_2} \\ b = \dfrac{x_1 y_2 - x_2 y_1}{x_1 - x_2}. \end{cases} \tag{1}$$

The Hough transform is the dispersion mapping from one to many while the Random Hough transform is the merger mapping from many to one. Merger mapping effectively reduces the amount of computation and improves the calculation speed. But there are many invalid mappings due to the random sampling. The introduction of linear gradient information can overcome the invalid mapping.

The randomized Hough transform algorithm based on gradient was applied to detect the center line of a crop row and test the detection of crop rows with three plant distributions, which are sparse, general and intensive.

2. Experimental methods

2.1. Image acquisition

The crop row in the actual field had features as follows. The row space was almost constant for the crop which was planted in rows or points. The seedlings of the crop were short and had a small projection area. The crop rows were not connected to each other. Due to variable light intensity and a complex soil background, images that were taken in natural outdoor fields were unstable. Meanwhile, a variable rate spray system based on machine vision required a quick real-time response. Research for real-time and environmentally adaptive plant location was crucial to the variable rate spray system.

The algorithm to detect the center line of the crop row should be faster and more adaptive for the complex actual field environment. The crop row images were collected by Samsung S500 digital camera in the experimental field of the China Agricultural University. The three selected distributions of plants in the row were sparse, general and intensive crops respectively. The detection processing is described as shown in Fig. 1.

2.2. Image preprocessing

In order to detect the center line of the crop row in field images, the field images should be preprocessed in several steps, which include image segmentation, region labeling, noise removal, and centroid coordinates calculation.

Step 1. *Image segmentation*

A threshold segmentation algorithm is widely applied in real-time system for its simplicity and speed. The greatest difficulties with the color image segmentation algorithm are to select the effective feature and determine the threshold. The crop-row image mainly consists of crops and background (such as soil). There is a big difference between the crop and background in color. Therefore, color was taken as the feature.

The gray images with bimodal histograms can be segmented effectively by a threshold segmentation algorithm. The color field images, which are taken under natural conditions, were grayed by several color features.

The histograms of these gray images were analyzed. The color features of the bimodal histogram were taken as the segmentation features. The segmentation thresholds were calculated by different methods. The gray images were segmented by different thresholds. The segmentation effect and speed were compared. The experimental results showed that the histogram of the grayed images by the color features (H, a*, I3 and Cr) were bimodal. The color features (H, a*, I3

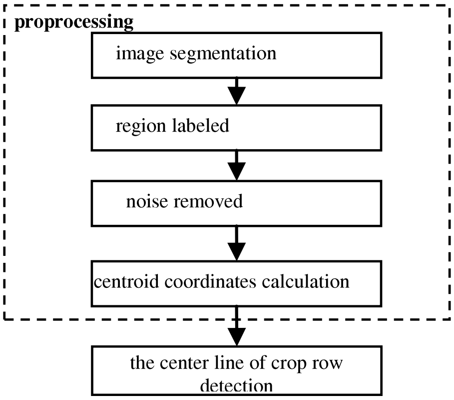

Fig. 1. The center line of crop-row detection processing.

and Cr) were selected as the segmentation features. There were several conclusions for the segmentation results. Firstly, the segmented images were satisfactory when the background was simple. Secondly, when the background composition was complex, the segmentation effect by the color feature H and Cr became bad and the segmentation effect by a* and I3 was unchanged, i.e. the segmentation by the color feature a* and I3 was more adaptive to the environment. At the same time, segmentation by Cr was fastest while a* was slowest.

As a conclusion, the color feature I3 was selected as the segmentation feature for the field image.

Step 2. *Regional mark*

The segmented image was a binary image. There were several regions in the binary image which corresponded to the crops. In order to extract the center of the crops, each crop should be marked and identified separately. Each crop was labeled by checking the connectivity of each image pixel and its neighboring pixels.

Step 3. *De-noising*

There were more labeled areas than the actual crop regions. After analysis of the labeled image, the difference was caused by noise. The noise areas were smaller than the crop areas in the field images. The noise was removed by the area properties of the labeled region.

The method to remove the noise in labeled images which was realized in Matlab was described as follows.

% The attribute values of the image were calculated and stored in label, where X was the labeled image

label=regionprops(X, 'all');

% The regions with areas less than 240 were selected. The area threshold value was set as 240 which was obtained after many tests,

idx=find([label.Area]>240);

% The regions with areas less than 240 were removed

X1=ismember(X, idx);

The crop region became much clearer after de-noising.

Step 4. *Calculation of centroid coordinates*

The de-noised images should be relabeled. The centroid coordinates of each region were calculated in Matlab as follows.

% The relabeled image was presented as $X2$

label1=regionprops(X2,'Centroid').

The center line of crop row was detected by the crop coordinates.

2.3. *Center line detection by the Randomized Hough transform*

The Randomized Hough transform was proposed by Xu and Oja [10] because of the deficiencies of the Hough transform. The problems in the Hough transform were solved by Randomized Hough transform fundamentally. The Hough transform is a distributed mapping from one to many, while the Randomized Hough transform is a combined mapping from many to one. The amount of calculation was reduced by the combined mapping effectively. Meanwhile the calculation speed was also improved. However, there were a great number of invalid mappings in the Randomized Hough transform for random sampling. The gradient of the line was introduced to reduce the invalid mapping.

3. Discussion

In order to test the adaptability of the algorithm for different situations, three kinds of field color images were selected in this paper. The images showed the different plant densities in crop rows (sparse, general and intensive), shown in Fig. 2(a). The center lines of the crop row were detected by the gradient-based Randomized Hough transform and the Hough transform respectively. The results are shown as Fig. 2(b) and (c).

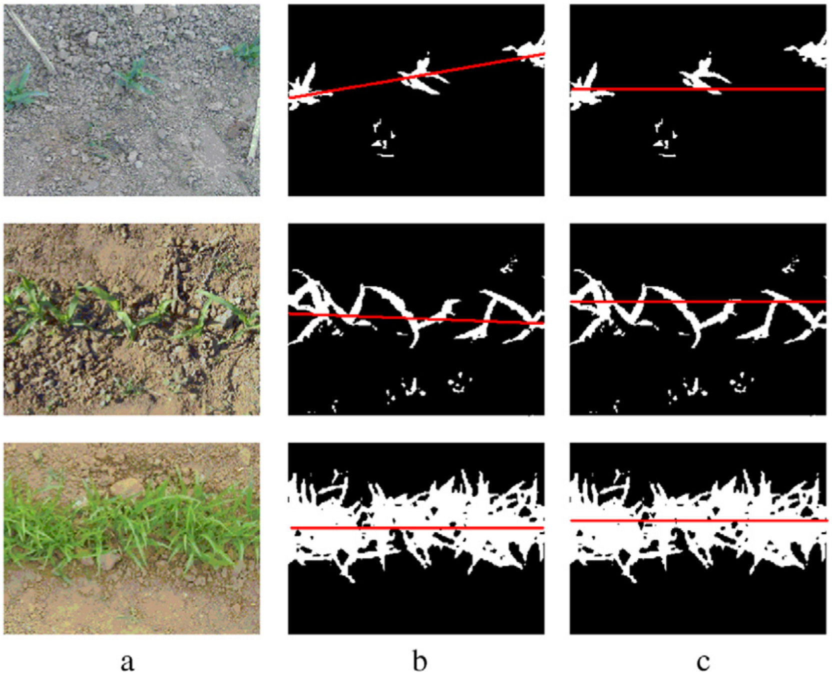

Fig. 2. The center line of crop-row detection results by gradient-based RHT and HT.

Table 1
Detection speed with different detection methods for different plant density.

Plant density	Sparse		General		Intensive	
Method	RHT	HT	RHT	HT	RHT	HT
Speed(s)	0.802	1.715	0.823	1.8103	0.831	1.8209

It was found that the detection with the gradient-based RHT was more accurate than the HT as for the different plant density distribution in crop row, in particular, there was a larger error with HT detection than the gradient-based RHT when the plants in the row were sparse. The algorithm calculation speeds were recorded and are shown in Table 1.

To detect a 400 $*$ 300 color image, RHT takes 0.802 s while HT takes 1.715 s. So, RHT improves the detection speed effectively.

By changing the mapping method, the gradient-based RHT reduced the computation and effectively improved the calculation speed. The gradient-based RHT could meet the real-time requirement of applications. At the same time the gradient-based RHT had a better adaptability for different distributions of crops in the crop rows.

4. Conclusions

Research for real-time and environmentally adaptive plant location is crucial to variable rate spray systems. The center line of the crop row should be detected to ensure spraying on-row and for vehicle navigation. The center line of the crop row is generally detected by an algorithm based on the Hough transform and its transformation. The Hough transform algorithm is slower because of the huge computation and is seldom applied in a real-time system. By changing the mapping method, the gradient-based RHT reduced the computation and effectively improved the calculation speed.

In order to test the effectiveness of the gradient-based RHT, three distributions of plants in row, being sparse, general and intensive crops were selected. The results showed that detection with the gradient-based RHT was more accurate than the HT for different plant density distributions in the crop row, in particular, there was a larger error with HT detection than the gradient-based RHT when the plants in the row were sparse. To detect a 400 $*$ 300 color image, RHT takes 0.802 s while HT takes 1.715 s. So, the RHT can improve the detection speed effectively. The gradient-based RHT can meet the real-time requirements for applications. Also, the same time gradient-based RHT had a better adaptability for different distributions of crops in the crop rows.

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