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Wheat rows detection at the early growth stage based on Hough transform and vanishing point

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ABSTRACT

A simple and effective wheat rows detection method is presented in this paper. It includes five steps: image segmentation, feature points extraction, candidate wheat rows estimation, vanishing point detection and real wheat rows detection. Firstly, a color image was converted into gray-level image and segmented in two parts, the foreground and background. Secondly, to extract feature points indicating centers of wheat rows, a moving window and multiple interlaced scanning strategies were constructed. Thirdly, the Hough transform method was employed to extract straight lines for estimating all possible candidate wheat rows. Fourthly, *k*-means clustering was performed to look for a clustering center representing the vanishing point. And lastly the real wheat rows were extracted based on the vanishing point. Test results indicate that the proposed method can effectively detect wheat rows at the early growth stage, and the detected rate is up to 90%.

1. Introduction

Precision agriculture is a new trend of agriculture development in the world. It is supported by information technology, positioning, timing, and quantitatively implements a set of modern farming operation technologies and management systems according to the spatial variation. As an important branch of precision agriculture, the autonomous navigation technology is becoming a more and more important research field and widely used in planting, fertilizing, weeding and harvesting, etc. (Perez et al., 2000; Wiles, 2011; Guerrero et al., 2012; Montalvo et al., 2013), since it can reduce operator fatigue, improve crop yields (Gan-Mor and Clark, 2001), lower production costs, minimize the wastage of pesticides required for the effective control of weeds(Felton and McCloy, 1992; Felton, 1995; Hague et al., 1997; Tian et al., 1999; Burgos-Artizzu et al., 2011) and improve the ecological environment (Han et al., 2004). In earlier literatures, numerous researchers and experts did a great deal of research and exploration (Onyango and Marchant, 2003; Tellaeche et al., 2008a,b; Burgos-Artizzu et al., 2009; Sainz-Costa et al., 2011).

In order to achieve the goal of autonomous navigation work, the most important step is to get the navigation information accurately. In view of the characteristics which most crops are cultivated in rows (Keicher and Seufert, 2000), we can detect the center lines of the crop rows to obtain the useful navigation information. In recent years, with the development of computer vision and information technology, automation work based on computer vision is becoming a hot spot in agricultural engineering field (Ruiz-Ruiz et al., 2009; Hemming and Rath, 2001).

1.1. Literature review

A lot of different methods have been proposed for detecting crop rows with image processing techniques (Zhang, 2011). Generally, their methods can mainly fall into three categories: methods based on linear regression; methods based on Hough transform and methods based on vanishing point.

The linear regression is often used to fit data to a straight line. For example, Billingsley and Schoenfisch (1997) presented a crop row detection method which applied linear regression based on information from three row segments to detect crop row guidance information. Montalvo et al. (2012) also applied linear regression to detect maize row in some high weeds pressure environment. The whole process was made of three steps: Firstly, the color images were transformed to gray-level images with enhanced green color plant index using $2g - r - b$. Secondly, the double thresholding approach was used and got better segmentation results, and lastly, a linear regression approach based on total least squares was applied for computing equations of straight lines associated to the

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crop rows. However, there were some prior knowledge was required: (1) the number of crop rows to be detected, (2) the expected location of each crop row in the image, and (3) the area to be explored in the image.

Hough transform (Hough, 1962) is also one of the most widely used methods for crop rows detection, especially in dealing with discontinuous rows or fields with weeds pressure because of its robustness. Numerous applications of crop rows identification based on Hough transform for automatic navigation can be found in literatures (Reid and Searcy, 1986; Marchant and Brivot, 1995; Torii et al., 1995; Marchant, 1996; Astrand and Baerveldt, 2005; Leemans and Destain, 2006; Van Evert et al., 2006; Slaughter et al., 2008; Ericson and Åstrand, 2009). The outstanding feature of Hough transform is to transform a difficult problem of line detection in image space to a relatively easy problem of point detection in parameter space. According to the coordinate transformation, the collinear points in image space correspond to concurrent lines in parameter space. In essence, Hough transform is a voting process where each point belonging to the patterns votes for all the possible patterns passing through that point. These votes are accumulated in an accumulator array, and the pattern receiving the maximum votes is recognized as the desired pattern (Chutatape and Guo, 1999). A threshold is usually required to clear the neighbourhood in the process of peak detection (Rovira-Más et al., 2005; Jones et al., 2009a,b). In Hough transform, however, two problems may exist: (a) the computational burden associated to its voting scheme may bring some adverse influences to real-time performances (Fernandes and Oliveira, 2008), (b) the number of detected peaks is usually far more than real lines to detect, and many alternative detected peaks are from data points which are on the same line voting accumulation. Moreover, even though an appropriate threshold is used to clear the neighborhood when estimating the parameters, some pseudo straight lines still cannot be eliminated because of the image noise. In our proposed method we constructed a moving window to extract some feature points indicating the centers of crop rows to overcome the first problem (in Section 2.3), and a vanishing point detection method was introduced to solve the second problem(in Section 2.5).

The basic idea of vanishing point method is that parallel straight lines in the three-dimensional space will intersect at a point in the two-dimensional plane corresponding to the camera projection. In farming, crops are usually cultivated in parallel rows and a camera is embedded in an agricultural machine, some researchers applied vanishing point methods to detect crop row. Pla et al. (1997) proposed an algorithm that extracted crop rows by finding the vanishing point. The processing of the images included the color image segmentation, which used a dichromatic reflection model (Pla et al., 1993), the extraction of the crop rows skeletons, the detection of straight lines from the skeleton curves and the tracking of the vanishing point. However, the method appears to heavily depend on the region skeletons, which are not always easy to extract, especially in the case of more weeds. Subsequently, Gée et al. (2008) applied a double Hough transform on the premise that only the crop rows converging to a vanishing point, the remainder lines (weed lines) were rejected. First Hough transform were performed to detect the main local maxima, second Hough transform used the main local maxima to find the global maximum (vanishing point of the crop rows) in Hough space, and then obtained the equation of the vanishing line. On this basis, all the maxima (Hough peaks) along the vanishing line in Hough space were detected, in consequence, the corresponding crop rows were extracted. Although the method gave reliable results, it is very dependent on the preprocessing stage, and some previous knowledge must be known, such as the camera parameters and inter-row spacing. Moreover, this approach increases the processing cost which will prevent its agricultural applications to achieve real-time performances.

1.2. Introduction of the proposed strategy

The object of our research is to explore an approach which is capable of detecting wheat rows under complex natural conditions at early growth stage and insensitive to shadow and inter-row space. The flow diagram of the proposed algorithm is schematically presented in Fig. 1, and consists of five steps. In the first step, the color indices $2G - R - B$ and Otsu's method were employed to obtain a binary image. Then, in order to obtain some feature points indicating the centers of wheat rows, a moving window was constructed. After this, all possible candidate wheat rows were estimated based on Hough transform. In the fourth step, a vanishing point detection method based on k-means clustering was performed to bring out a cluster center representing the vanishing point. Lastly, the pseudo straight lines were removed and the real wheat rows obtained based on vanishing point. One contribution of our research is that an image feature points extraction method for estimating the center points of wheat rows, which reduces dramatically the computation burden. Another contribution is that we introduce a line detection algorithm for wheat rows detection which is a perfect fusion of the merits of Hough transform and vanishing point detection. The proposed strategy not only avoids the difficulty of peak detection in Hough transform, but also overcomes the complexity of the other methods which are based on vanishing point.

1.3. Outline of the paper

This paper is arranged as follows. Section 1 gives the general introduction. The details of materials and methods are presented in Section 2. Section 3 shows the results and discussions of the proposed algorithm. The conclusions are displayed in Section 4.

2. Materials and methods

2.1. Image source and experimental equipment

The images in this research were collected from National Research and Demonstration Base of Precision Agriculture in Xiaotangshan Town and Experimental Field of Chinese Academy of Agricultural Sciences in Beijing. All images belong to wheat crops at the early growth stage from October 2012 to February 2013. In order to test the effectiveness of the method, two different kinds of cameras were used to capture images: a Samsung S750 color camera and Blackberry Mobile Phone Z10. The cameras were set at 130–170 cm above the ground looking forward and down at an angle of 30–45° to the vertical, yaw was −15° to 15°, and roll was about −10° to 10°.

The digital images were saved with the JPEG format. Four types of images were used for image processing and analysis. For Samsung S750 color camera, the resolutions of the captured images are 768×1024 and 1024×768 pixels. For Blackberry mobile phone, they are 3264×1836 and 1836×3264 pixels. After the JPEG images were obtained, it was necessary to carry out the down sampling processing to reduce the computational load. Here, the classic resampling method—bilinear interpolation method was employed due to its simplicity and effectiveness. After bilinear interpolation, the image sizes shrank from the original sizes of 768×1024, 1024×768, 3264×1836 and 1836×3264 pixels to 480×640, 640×480, 640×360 and 360×640 pixels, respectively. They were captured under different conditions such as different illumination, different wheat density and different field soil conditions. Fig. 2 shows an example of color image with a resolution of 640×480 pixels.