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Center-based clustering for line detection and application to crop rows detection

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ABSTRACT

This paper proposes 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 $\mathcal{A}$ and on the DIRECT algorithm for global optimization. The proposed method was modified for solving the problem of detecting crop rows in agricultural production. This modification can recognize crop rows with a high accuracy, and the corresponding CPU-time is very acceptable. The method has been tested and compared on synthetic data sets with the method based on Hough transformation. The efficiency of this method might be significantly improved in direct application. The proposed method has been used in this paper for the case of two or three crop rows. The generalization to several crop rows is also given in the paper, but was not implemented. Also, the method could be expanded in case when the number of crop rows is not known in advance.

1. Introduction

Line segment or line detection problem has many applications. Let us mention one that has special importance in agricultural production. The processes of planting, fertilization, plant protection and finally harvesting are the most important processes in agriculture that can be automated. During any of the mentioned processes humans must handle a machine (a tractor, for example) with a high degree of precision and repeat the same activity for several hours, which can be very exhausting. With acceptably accurate crop rows detection it is possible to automate machine work which is usually very exhausting and sometimes too demanding for humans.

The mentioned automation processes of machines in agricultural production have been subjects of many papers. One of the first approaches to solving this problem is a Hough transform-based method. (Marchant, 1996) proposed a method based on Hough transformation, which uses the information about the number of crop rows making this technique very tolerant to problems like missing plants and weeds. The method has been tested on cauliflowers, sugar beet and widely spaced double rows of wheat. (Bakker et al., 2008) transformed captured color images to gray-scale images which have good contrast between a plant and the background. Sugar beet rows have been detected using gray-scale Hough transformation. (Ji and Qi, 2011) proposed a center line crop rows detection method using gradient-based random Hough transformation. The method has been tested on sparse, general and intensive plant distribution and the results have shown that the proposed method is faster and more accurate than general Hough transform-based algorithms. An adaptation of Hough transformation applied to soil and chicory rows detection was proposed by (Leemans and Destain, 2006). They used neural networks for plants detection and adapted Hough transformation for rows detection. In this adaptation, the Hough transformation method uses theoretical crop row position and direction for reference in Hough plane. Deviation of detected crop rows from the reference was a few centimeters and authors found this compatible with the application. (Rovira-Mas et al., 2005) presented a combination of Hough transformation and connectivity analysis for finding a pathway between crop rows.

Other possibilities for crop rows detection are filter-based methods. The method for hoe guidance based on the extended Kalman filter was proposed by (Tillett and Hague, 1999). The prediction of rows position has been calculated according to the previous state and inputs using the Kalman filter and corrected by least squares incorporation of new observations. This method is very sensitive to the presence of shadows. (Olsen, 1995) proposed a method for detecting centre position of crop rows using an infrared filter based on summation of pixel gray values. The method is not sensitive to shadows while lateral winds and lateral

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illumination cause offset in the calculated rows position. (Hague and Tillett, 2001) proposed a combination of a (Olsen, 1995) method and a Kalman filter. The method is applicable to images with presence of shadows unlike the method presented earlier (Tillett and Hague, 1999).

There are several other approaches for crop rows detection like methods based on vanishing points or linear regression. (Pla et al., 1997) presented a method for guiding a crop rows navigation vehicle based on a scene structure building using a vanishing point. Feature extraction was done by a method based on region skeletons. The method does not work well when an image is captured at the end of the field where the remaining length of the rows is short. The method for detecting crop rows without image segmentation was proposed by (Søgaard and Olsen, 2003). Computation of line parameters was done by weighted linear regression and the method has been tested on real images. (Montalvo et al., 2012) proposed a new method for crop rows detection in maize fields with a high presence of weeds. The method is based on three steps including image segmentation, double thresholding and linear regression. The Excess Green vegetation index has been used for transforming captured RGB images to gray images and double Otsu thresholding has been applied for separating weeds and crops. For calculating line parameters associated to the crop rows, linear regression based on total least squares has been used. The main finding of this paper is double thresholding used for separating weeds and crops. The method has been favorably compared to a classical Hough approach measuring effectiveness and processing time. A new method for crop rows detection in maize fields based on linear regression and Theil-Sen estimator was proposed in (Guerrero et al., 2013). Crops and weeds are detected by using the Otsu thresholding method and the detection of crop rows is based on mapping the expected crop lines onto image and applying the Theil-Sen estimator to adjust them to the real ones.

In our paper, we first consider the problem of recognizing several lines in general position (Section 2) and propose a new cluster-based incremental method of searching for approximate lines (Section 2.3.2). After that, in Section 3 we propose a new method for crop rows detection as a combination of total least squares linear regression and a modification of the previously mentioned center-based incremental method. In Section 4, the proposed methods are tested and compared with the Hough transform-based algorithm on synthetic data simulating various real situations.

2. Line detection problem

Let us notice first that, without loss of generality, we can suppose that the arbitrary line in the plane is given by

$$ax + by - c = 0, \quad a^2 + b^2 = 1, \quad c \geqslant 0. \tag{1}$$

Let us suppose that the data point set $\mathcal{A}$ is given whose elements derive from previously unknown lines. Thereby, the number of lines can, but need not be, known in advance. On the basis of the given data point set $\mathcal{A}$, the lines could be reconstructed.

2.1. Data point set construction

The line detection problem shall first be considered on the data point set deriving from lines in general position. Let $I = \{1, \ldots, m\}$ be the set of indices and

$$\mathcal{A} = \{T_i = (x_i, y_i) \in \mathbb{R}^2 : i \in I\} \subset R \tag{2}$$

the data point set contained in the rectangle $R = [x_{min}, x_{max}] \times [y_{min}, y_{max}]$. The data point set $\mathcal{A}$ is generated by k lines

$$p_j: \quad a_j x + b_j y - c_j = 0, \quad a_j^2 + b_j^2 = 1, \quad c_j \geqslant 0, j \in J = \{1, \ldots, k\}, \tag{3}$$

in the following way. First, we choose interval $[y_{min}, y_{max}] \subset \mathbb{R}$ and for each $j \in J$ we define $m_j \geqslant 3$ equidistant spaced numbers $\eta_1, \ldots, \eta_{m_j} \in [y_{min}, y_{max}]$ and the set (see Fig. 1)

$$\mathcal{A}_j = \{(\xi_i^{(j)}, \eta_i^{(j)}) + \epsilon_i^{(j)}(a_j, b_j) : \xi_i^{(j)} = \frac{1}{a_j}(c_j - b_j \eta_i^{(j)}),$$
$$\epsilon_i^{(j)} \sim \mathcal{N}(0, \sigma^2), \quad i = 1, \ldots, m_j\}.$$

The data point set $\mathcal{A} = \bigcup_{j=1}^{k} \mathcal{A}_j$ consists of $m = \sum_{j=1}^{k} m_j$ data points $T_i = (x_i, y_i) \in [x_{min}, x_{max}] \times [y_{min}, y_{max}]$, where $x_{min} = \min_{i,j}\{\xi_i^{(j)} + \epsilon_i^{(j)} a_j\}, x_{max} = \max_{i,j}\{\xi_i^{(j)} + \epsilon_i^{(j)} a_j\}$. On the basis of the given data point set $\mathcal{A}$, lines $p_1, \ldots, p_k$ should be reconstructed.

2.2. Hough transformation method for line detection

Line detection by the Hough transform-based method (Duda and Hart, 1972; Leemans and Destain, 2006) is achieved by searching for the maximum in the Hough plane (accumulator), which represents the transformation of the input image. Each point $T = (\xi, \eta) \in \mathcal{A} \subset \mathbb{R}^2$ in the Hough plane is represented by all possible lines given in Hesse normal form passing through the point T, i.e. the set

$$\{(\alpha, \delta) \in \mathbb{R}^2 : \xi \cos \alpha + \eta \sin \alpha - \delta = 0\}.$$

In this way, some line p in the plane $\mathbb{R}^2$ is represented by a pair (α, δ) in the Hough plane, and some point $T \in \mathbb{R}^2$ is represented by the sequence of points in the Hough plane. Points that in the original image lie on a line increase the intensity of the point that represents that line in the Hough plane. The algorithm for line reconstruction, which is based on recognizing the most intensive points in the Hough plane will be hereinafter simply referred to as HTA.

2.3. Cluster-based line detection

Line detection problem can also be considered (Bagirov et al., 2013; Späth, 1983; Yin, 1998) as a data clustering problem of the set $\mathcal{A}$ in k nonempty disjoint subsets (clusters) $\pi_1, \ldots, \pi_k$ such that

$$\bigcup_{i=1}^{k} \pi_i = \mathcal{A}, \qquad \pi_r \cap \pi_s = \emptyset, \quad r \neq s, \qquad |\pi_j| \geqslant 1, \quad j = 1, \ldots, k. \tag{4}$$

Such partition will be denoted by Π, and the set of all partitions of the set $\mathcal{A}$ consisting of k clusters $\pi_1, \ldots, \pi_k$ will be denoted by $\mathcal{P}(\mathcal{A}; m, k)$. Clustering or grouping a data set into conceptually meaningful clusters is a well-studied problem in recent literature, and it has practical importance in a wide variety of applications such as medicine, biology, pattern recognition, facility location problem, text classification, information retrieval, earthquake investigation, understanding the Earth's climate, psychology, ranking of municipalities for financial support, business, etc. (Kogan, 2007; Liao et al., 2012; Mostafa, 2013; Pintér, 1996; Reyes et al., 2013; Sabo et al., 2011; Sabo et al., 2013; Scitovski and Scitovski, 2013).

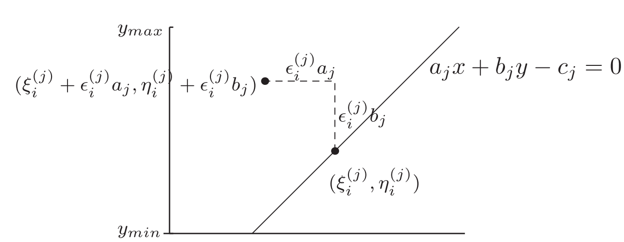

Fig. 1. Data generating.