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An Efficient Crop Row Detection Method for Agriculture Robots

Chunling Tu
Department of Computer System Engineering
Faculty of Information Communication Technology
Tshwane University of Technology
Pretoria, South Africa 0001

Barend Jacobus van Wyk, Karim Djouani, Yskandar Hamam
F'SATIE
Faculty of Engineering and Built Environment
Tshwane University of Technology
Pretoria, South Africa,0001

Shengzhi Du
Department of Mechanical Engineering, Tshwane University of Technology, Pretoria, South Africa 0001

***Abstract*—In this paper an efficient crop row detection method is proposed for vision-based navigation for agriculture robots. In the proposed method, no low level features (such as edges and middle lines of the images) are needed. So the complex algorithms for edging and matching (e.g. the Hough transform) are avoided, which greatly saves the computation loads. Instead, a flexible quadrangle is defined to detect the crop rows. The proposed method moves, extends or shrinks the flexible quadrangle to localise the crop rows in the captured frames. The experiments demonstrate that the proposed method is effective with high time efficiency and detection accuracy.**

Keywords: Crop Row Detection, Hough transform (HT), Computer Vision, Agriculture Robots.

I. Introduction

Vision based agricultural robot navigation has got extensive attention because of its contributions to the automation of modern agriculture. Various automatic agricultural robots [1][2][3] were proposed with different navigation techniques. Zhao et.al [1] designed a vision navigation system of agricultural vehicles where the lateral and heading deviation are controlled via the recognition of crop rows as navigation paths. The Hough transform was employed to detect the crop rows [1].

In this type of navigation, it is usually needed to analyse the complex features such as the edges, and/or middle lines of the crop rows from high dimensional data, that is the images captured by cameras mounted on the robots. The computation load required to analyse the images is one of the main constraints. A commonly used framework mainly contains two steps: firstly achieving low level information, such as edges and middle lines; then by matching the low level information, the position and orientation of the crop rows [4][5] were obtained for navigation. Complex methods such as edging operators[6][7], the Hough transform[2][3][6][7][8][9], and some other feature matching algorithms are widely used. For example, in [1] the full colour images are firstly converted to grey level images followed by the threshold segmentation and erosion. The centre lines are then used to present the crop rows which are localised by the Hough transform [1]. In [2][8], the centre points of each crop row were detected by scanning every horizontal line pixels, then the Hough transform was employed to fit the centre points to a straight line which was considered as the navigation path. Dilation was used in [7] to facilitate edge detections. All these methods have high computation requirement, which adversely affects the efficiency of the robots.

In this paper, an efficient method is proposed without extensive needs of edging and matching operations. A flexible quadrangle is defined which could be moved, extended, and shrunk to localise and trace the crop rows during the proceeding of robots. The proposed method is based on binary images, the detection of edges or middle lines of the crop rows is avoided, therefore, greatly saves the computation loads.

II. Image Pre-processing

A. *Convert full colour images to grey level images*

To prevent information missing, most cameras used in agricultural robots have full colour space with red, green, and blue (RGB) colour contents. However, for most image processing operations, the grey level images are more convenient. So it is very common to convert full colour images to grey scale before further processing. For specific applications the method of converting between these two colour spaces should be considered according to the chromatic coordinates of objects.

In agriculture applications, crops and/or weeds are commonly targeted. Comparing to the background soil, the green chromatic coordinate of these plants are dominate. Therefore, by outlining the green component while depressing other two, it is easier to isolate these objects from background. It was reported that 2G-R-B colour space is robust in identifying weeds from background soil under both unshaded and shaded sunlit conditions[10].

When the strawberry field is considered, Wang et.al [2] compared the grey scale conversion according to three different colour spaces (1.5G-R-B, Lab-a colour space, and G-R colour space) and mentioned that the 1.5G-R-B is better than others.

In this research, there exist the uncertainties of shades and crop categories which means the robust 2G-R-B colour space is more feasible.

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B. Binarization

In most objects recognition and tracing applications, binarization on a grey scale image is commonly needed to isolate objects from background. It is critical to consider the choice of threshold(s), because it has significant impact on the binary image quality and computation loads. Otsu [11] proposed a method to chooses the threshold by minimising the intra-class variance of the black and white pixels. This method is widely used in image processing applications. In this research, Otsu's method is employed in binarization.

III. The Proposed Method

In this research, the images are captured by the camera mounted on the agricultural vehicle. Because of the perspective deformation, the crop rows in the images appear as quadrangles with the far end narrower than the near end. Figure 1(a) depicts this deformation. To navigate the vehicle, these deformed quadrangles are supposed to be localised.

A. A Flexible Quadrangle

During the proceeding of the vehicle, orientation and position of the camera are affected by the driving control actions and the path profile, which results in the continuous changes of the position of these quadrangles in the images. So identifying and tracing the quadrangles are the core tasks of navigation. In most literatures, edging or centre points detecting methods are employed on the binary images, then line fitting algorithms or Hough transforms are used to localised the crop rows. These operations commonly require high computation loads.

In this paper, a method of localising crop rows by flexible quadrangles is proposed without needs of edging or line fitting operations. The left and right boundaries of the quadrangle are split into 4 sections (denoted by boundary boxes, that is, S_1, S_2, S_3 and S_4) as shown in Figure 1(b). The width of each boundary box is 1 pixel. The positions of these boxes are modified during the proceeding of the vehicle to make sure the quadrangle tightly contains the crop row (It should be noted that, for some specific applications, the gap between crop rows might be more feasible to be detected).

The boundary boxes are represented by their corners, that is

$$S_1: \quad \{(x_1^1, y_1^1), (x_1^2, y_1^2), (x_1^3, y_1^3), (x_1^4, y_1^4)\}, \tag{1}$$

$$S_2: \quad \{(x_2^1, y_2^1), (x_2^2, y_2^2), (x_2^3, y_2^3), (x_2^4, y_2^4)\}, \tag{2}$$

$$S_3: \quad \{(x_3^1, y_3^1), (x_3^2, y_3^2), (x_3^3, y_3^3), (x_3^4, y_3^4)\}, \tag{3}$$

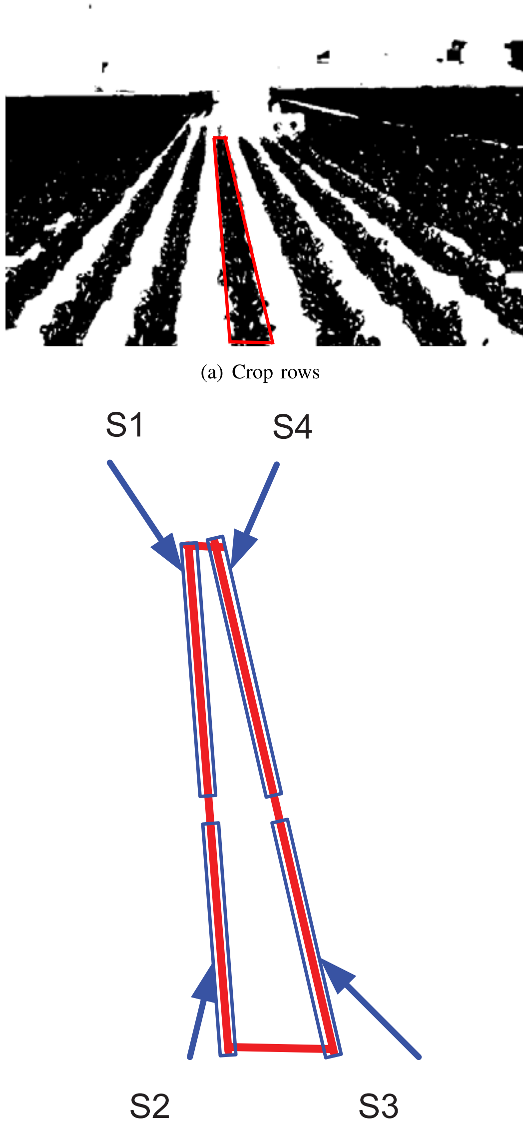
and

$$S_4: \quad \{(x_4^1, y_4^1), (x_4^2, y_4^2), (x_4^3, y_4^3), (x_4^4, y_4^4)\}. \tag{4}$$

As shown in Fig.2, the corners of a boundary box are named in the anti-clockwise style.

Since the width of boundary boxes is fixed, when a boundary box is moved to horizontally by m pixels, then the coordinates of its corners have the following changes:

$$\begin{array}{ll} x^i = x^i + m & i = \{1, 2, 3, 4) \\ y^i = y^i & i = \{1, 2, 3, 4). \end{array} \tag{5}$$



(a) Crop rows

(b) Quadrangle boundary boxes

Fig. 1. The crop rows are represented by deformed quadrangles

Similarly, when it is moved vertically by m pixels

$$\begin{array}{ll} x^i = x^i & i = \{1, 2, 3, 4) \\ y^i = y^i + m & i = \{1, 2, 3, 4). \end{array} \tag{6}$$

In the proposed method, only the horizontal movements are considered.

B. The hits and mis-hits of boundaries

To verify whether the quadrangle tightly contains the area of crop rows (or the gap between crop rows when it is feasible for specific applications), the boundary boxes are checked for "hit" or "mis-hit" the crop rows according to the following criteria.

- Criterion 1 (hit): boundary S_i hits the crop row if and

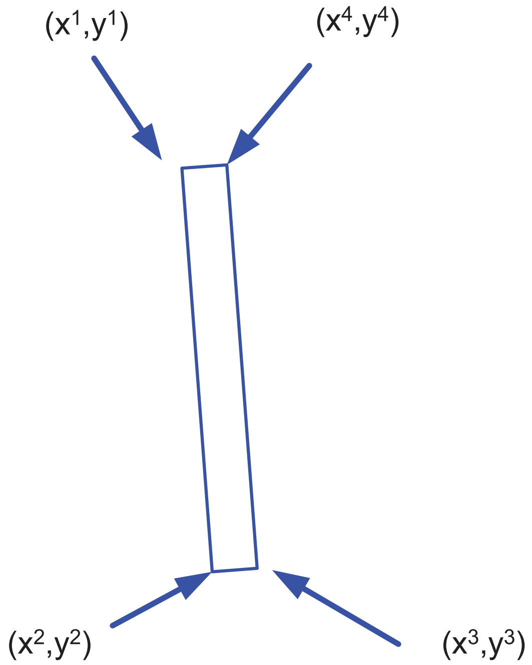


Fig. 2. The corners of a boundary box

only if

$$\Sigma_{n=1}^{N} p(n) > N/2, p(n) \in S_i; \quad (7)$$

- Criterion 2 (mis-hit): boundary S_i mis-hits the crop row if and only if

$$\Sigma_{n=1}^{N} p(n) < N/4, p(n) \in S_i; \quad (8)$$

where N is the number of pixels contained in the boundary box S_i, $i = 1, \cdots, 4$, $p(n)$ is the value of each pixel (black pixel has value of 1, and white pixel 0).

Criterion 1 means the boundary box hits the crop row when more than half of its pixels are black (that is, most of the pixels in the box belong to the crop row). Criterion 2 shows that if less than a quarter of its pixels belong to the crop row then the boundary box is considered mis-hitting the target.

According to the situations of hitting and mis-hitting, the boundary boxes are moved in the following rules to make sure the quadrangle tightly contains the targets.

- if boundary box S_i hits the crop row then move it away from the crop row. That is

$$\begin{cases} x_i^j = x_i^j - 1, \text{for } i = 1, 2, j = 1, 2, 3, 4 \\ y_i^j = y_i^j, \text{for } i = 1, 2, j = 1, 2, 3, 4 \end{cases}, \quad (9)$$

$$\begin{cases} x_i^j = x_i^j + 1, \text{for } i = 3, 4, j = 1, 2, 3, 4 \\ y_i^j = y_i^j, \text{for } i = 3, 4, j = 1, 2, 3, 4 \end{cases}. \quad (10)$$

- if boundary box S_i mis-hits the crop row then move it towards the crop row. That is

$$\begin{cases} x_i^j = x_i^j + 1, \text{for } i = 1, 2, j = 1, 2, 3, 4 \\ y_i^j = y_i^j, \text{for } i = 1, 2, j = 1, 2, 3, 4 \end{cases}, \quad (11)$$

$$\begin{cases} x_i^j = x_i^j - 1, \text{for } i = 3, 4, j = 1, 2, 3, 4 \\ y_i^j = y_i^j, \text{for } i = 3, 4, j = 1, 2, 3, 4 \end{cases}. \quad (12)$$

To be noted that in the rules (9), (10), (11) and (12), only the horizontal position (i.e. x axis) of the box is changed. The vertical position of S_i (i.e. y coordinate) is not changed.

From the rules one finds the following modifications of the flexible quadrangle can be obtained:

1) Horizontal moving. When all the 4 boundary boxes have the same movement in the same way, the quadrangle does not change its shape but move to the right/left.
2) Shrinking. When the boundary boxes in the left side (S_1 and S_2) and the ones in the right side (S_3 and S_4) move towards to each other. The area of the quadrangle is decreased.
3) Shrinking. When the boundary boxes in the left side (S_1 and S_2) and the ones in the right side (S_3 and S_4) move away from each other. The area of the quadrangle is increase.
4) Orientation changing. When the upper boundary boxes (S_1 and S_4) and the lower ones (S_2 and S_3) have different movements, the quadrangle will change its orientation.

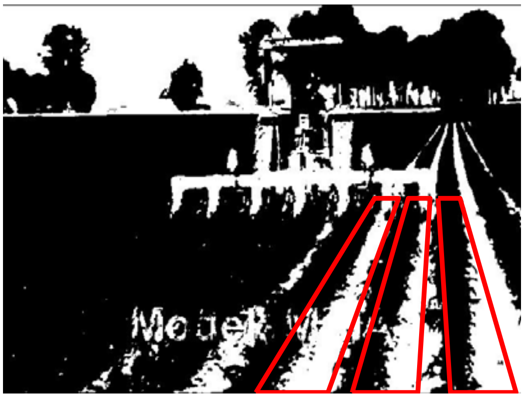
These changes are not all the potential modifications of the quadrangle. The combinations of them could result in the high flexibility of the quadrangle which is needed for accurately localising and tracing target even the crop rows might not straight and discontinuous.

C. The steps of the proposed method

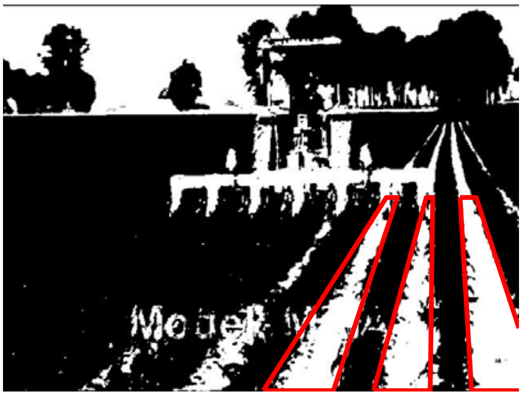
The following steps summarise the proposed method

1) Initialisation of quadrangles. For the very first image, the quadrangle positions and dimensions are given by other methods or manually indicated.
2) Image pre-processing. During the proceeding of the vehicle, for each image, obtain the grey scaling image using 2G-R-B colour space and binarize the grey scaling image using Otsu's threshold.
3) Check the hitting and mis-hitting conditions of the boundary boxes according to the criteria (7) and (8).
4) Modify the position of boundary boxes according to the rules (9)-(12).
5) For the following image, keep the boundary box positions and dimensions and repeat from step 2).

To be noted that in the proposed method the boundary box positions and dimensions can be kept for the next image, this is because the deviation of crop rows in adjacent frames is rather small since the vehicle moves slow and the sampling rate of camera is relatively high. In fact, the vehicle only moves very small distance during a sampling period.

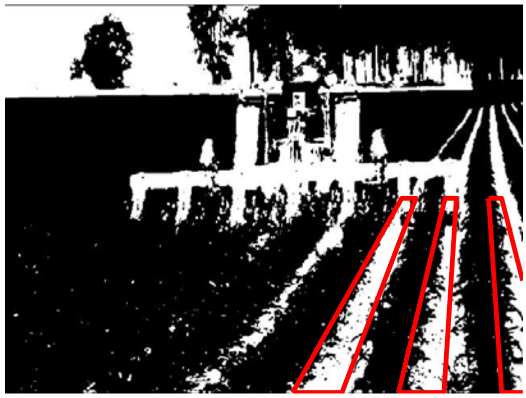


(a) The first frame initialised quadrangles

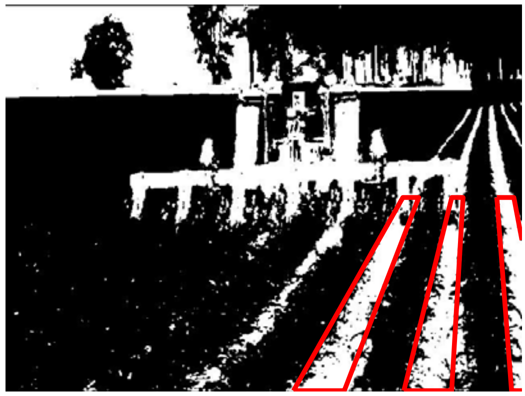


(b) Detected gaps in the first frame

Fig. 3. The gaps are initialised with errors but detected correctly



(a) The 250th frame initialised quadrangles



(b) Detected gaps in the 250th frame

Fig. 4. The gap positions are kept from last frame with errors but detected correctly

IV. Industrial Applications

To validate the performance of the proposed method, a video captured on a farm field with complex background (trees and agricultural machinery) is considered. The video has 25 frames per second. Each frame has 640x480 pixels in full colour space (RGB24).

At the very first frame, the quadrangles are roughly initialised with significant errors as shown in Figure 3(a). The proposed flexible quadrangle method is employed on this initialised image. From Figure 3(b) one can find that the quadrangles tightly contain the crop rows which means the crop rows are identified and located with high accuracy. For this purpose, the quadrangle is shrunk, moved, and the orientation also changed, then the initialisation errors are eliminated effectively.

Figure 3(b) demonstrates the performance of the proposed method when the quadrangles are kept from the last frame. To make the experiment more challengeable, the samples are taken very 5 frames, that is the frame rate is 5 frames per second. This under-sampling allows the vehicle carrying the camera cover a bigger distance during the sampling period, therefore, the differences between two adjacent frames becomes significant. As shown in Figure 4(a) the quadrangles inherited from the last frame (i.e. 5 frames before in the original video) lead to significant errors. From the detection results depicted in Figure 4(b), the proposed method still have very good performance.

It should be noted that in the experiments, the gaps between crop rows are detected instead of crop rows, which is because the gaps have fewer pixels than the crop rows and are more distinct. Of course for some other application the crop rows might be easier to detect than the gaps.

V. Comparison with Other Methods

To show the outstanding efficiency of the proposed method, a comprehensive comparison among some of the existing methods is considered including the following criteria.

- Whether point-wise operation is employed?
  Since point wise operations consider each pixel when achieving higher level information, therefore, they are low efficient. A typical example of this type of operations the is Hough transform. Most neighbour filters also fall in this category.
- Whether edging algorithm is employed?
  Edging algorithm usually need to obtain the edge information based on gradient or other heuristic clue among

TABLE I
COMPARISON OF THE PROPOSED METHOD AND SOME EXISTING WORKS

Methods	Point-wise	Edging	Erosion or dilation	Line matching
The proposed method	No	No	No	No
[6]	No	No	No	Yes
[2]	Yes	No	No	Yes
[8]	No	No	No	Yes
[7]	Yes	Yes	No	Yes
[1]	Yes	No	Yes	Yes
[3]	Yes	No	Yes	Yes

pixels and their neighbours. This kind of operations have high time consumption.

- Whether mathematical morphology operations such as erosion and dilation are employed?
  Erosion and dilation usually need many iterations before the desired results could be obtained.
- Whether line matching or the Hough transform employed to obtain the final guide path?
  These methods usually only need low computation as long as the discrete points are known. But the discrete points are usually obtained in the cost of other complex algorithms, such as middle point detection for crop rows.

From the comparison one finds that the proposed method avoided all of these computational intensive operations. However, other methods depend on more or less of these operations.

VI. CONCLUSION

This paper proposed a method aims to identify and trace the crop rows from the videos captured for farm fields. The method has high time efficiency because neither complex edging nor segmentation methods is employed, and no high level operations such as the Hough transform are needed. The real world video validated the performance of the proposed method.

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