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Full Length Research Paper

The mature wheat cut and uncut edge detection method based on wavelet image rotation and projection

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For combine harvester, automatically and promptly recognizing the cut and uncut edge of guideline is the key technology to realize autonomous navigation based on vision machine. One novel method termed wavelet image rotation and projection algorithm has been established. It includes the following essential steps. Firstly, 2^3 scale of wavelet transforming was selected because of intrinsic characteristics of multiscale and multiresolution of wavelet transforming, and the low frequency wavelet image was obtained which was used to rotate transform to computer column average values. To achieve the best match of rough-division and elaborate-division, and to reduce processing time, the initial given rotation angle was 5°, and the final rotation angle was 1° based on former rotating transform. Then the rotation and projection matrix R including the column average values and the enumeration angles was achieved. Finally, the difference in rotation and projection matrix came from R 's row vectors' difference operation to locate extremum values, the heading angle and lateral position can be found out. The method result shows the accuracy of recognizing cut and uncut line, achieve the effect with 95.6%, the average processing time is 109.3 ms per frame, and the algorithm owns the characteristics of anti-color-disturbance, independent on the whole brightness and high robustness. The method can also be applied to detect the field end line.

Key words: Autonomous guidance, wavelet transform, rotation and projection matrix, mature wheat image, combine harvester.

INTRODUCTION

Agriculture today is driven to feed an increasing population with a declining farm work force at a lower cost. The drive to decrease costs and increase production has provided inroads for new technology in agriculture. The cost and production goals require technological innovations to maximize efficiency.

With the development of precision agriculture for almost 20 years, researchers in the relational field have done research on the machine vision to improve the system's real time performance, high precision and high reliability. Agriculture machine itself walking automatically by the crop line or cut/uncut edge and owning high efficiency are the main objects of vision navigation; researchers who work to improve agriculture machine's intelligence.

It is difficult to get the navigation guidance from the non-structure crop image with lots of noise information. Furthermore, the field environment is variable and complicated. Researchers in the relational field around the world have done much deep work to improve the agriculture vision system's robustness, precision and real time performance. To summarize the prior methods for recognizing the navigation guidance, they include three types: the first type mainly employs image segmentation, edge detection such as Robert, Sobel, Prewitt, Kirsch and Gauss-Laplace algorithm, grey level calculation and morphologic processing and so on (Zhang et al., 2006; Zhao et al., 2006; Li et al., 2008). These traditional methods have good processing effect on images

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Abbreviations: SLHT, Scan line and Hough transform; **ROI,** region of interest.

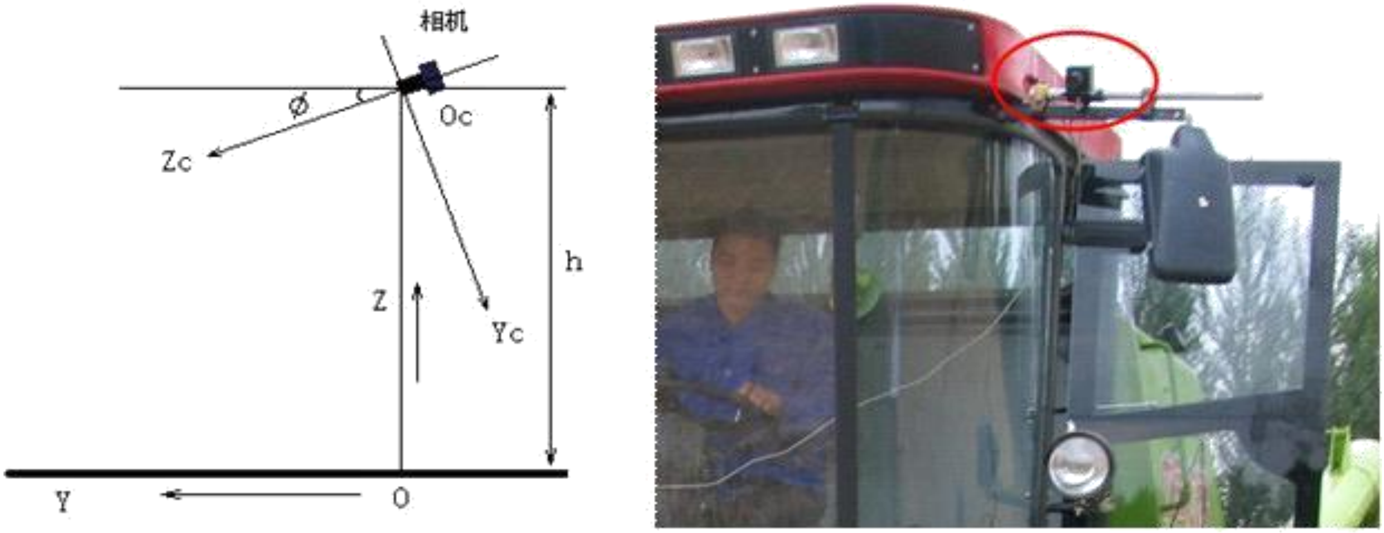

Figure 1. Camera installation and coordinate systems, the right are the combine harvester platform.

snapped in the manual designed light and background (Chen et al., 2006). However, for the nature crop field such as mature wheat, the grabbed images are affected by weather, facing sun, back sun and other objects such as human, tree and telegraph pole. It is difficult to obtain the navigation guidance applying traditional methods. The second type is termed scan line and Hough transform (SLHT). The main procedure of this method is that regarding image's column or row data as the base unit, scanning every row or column, finding out the edge candidate point, collecting all the points and through the least square method or Hough transform or its improvement, pass one point Hough transform, the navigation line can be found out (Zhang et al., 2007; Han et al., 2004). Zhao et al. (2006) and Zhang et al. (2007) utilized this way to get the non-structure road guidance line and plow gutter line. Leemans et al. (2006) used Hough transform (HT) and mean-shift algorithm to locate seeds in one row. The third type mainly uses some classical algorithm such as wavelet analysis, fuzzy logic recognition (Zhang et al., 2004; Benson et al., 2003), K-means clustering algorithm (Han et al., 2002) and dynamic window technology (Yang et al., 2004) to extract the guidance line from the region of interest (ROI). Chen et al. (2003) utilized differential operator, brightness analysis and color analysis to extract the target in water and used more than one point HT to get the target line for the paddy field robot to automatically transplant rice seedlings and manage the field. Zhou et al. (2003) used the multi-resolution characteristic of wavelet transform to detect the cole field image large edge.

In this paper, a novel method for mature wheat cut/uncut edge line detection, termed wavelet image rotation and projection algorithm, which is based on the former research on the various crop lines, ridge rows, plow gutter lines and the marker lines between worked and un-worked area has been put forward. Through this algorithm, the cut/uncut edge of mature wheat image can be recognized and located in 110 ms, and it can calculate two important control parameters, navigation heading angle and lateral position. The algorithm, based on wavelet transform and rotation transform, has been tested by lots of mature wheat images and videos. Its performance has been analyzed and discussed.

MATERIALS AND METHODS

Camera location and field data collection

In this project the camera is DH-HV1302UC with USB interface, equipped with Computer M0814-mp lens whose focus length is 8 mm. The output of the camera with 15 frames per second is color image with the resolution of 800 pixels (horizontal) by 600 pixels (vertical). The camera was installed on one steel shaft which is fixed on the XinJiangII combine harvester cab head. The vertical distance h from the lens center to the ground is 3.5 m, and the tilt angle Ø is 30.5°. Figure 1 shows the position that camera has been installed and coordinate systems X, Y, Z are the camera coordinate system, O_C is the origin, and the right direction of lens plane is X_C direction. X, Y, Z are the world coordinate system, O is the projection point of O_C projecting to the ground, and the X direction is same as X_C. In this project, the processing computer is configured with Core2 Duo CPU2.1GHz and 1GB memory. In the sunshine, cloudy, facing sun and back to sun, 800 images had been grabbed (it had been saved as video format).

Algorithm description

Wavelet image rotation and projection algorithm includes four key steps:

1. Wavelet transform of mature wheat gray image.
2. Wavelet image rotation transform.
3. Structure the rotation and projection matrix, and its different matrix.

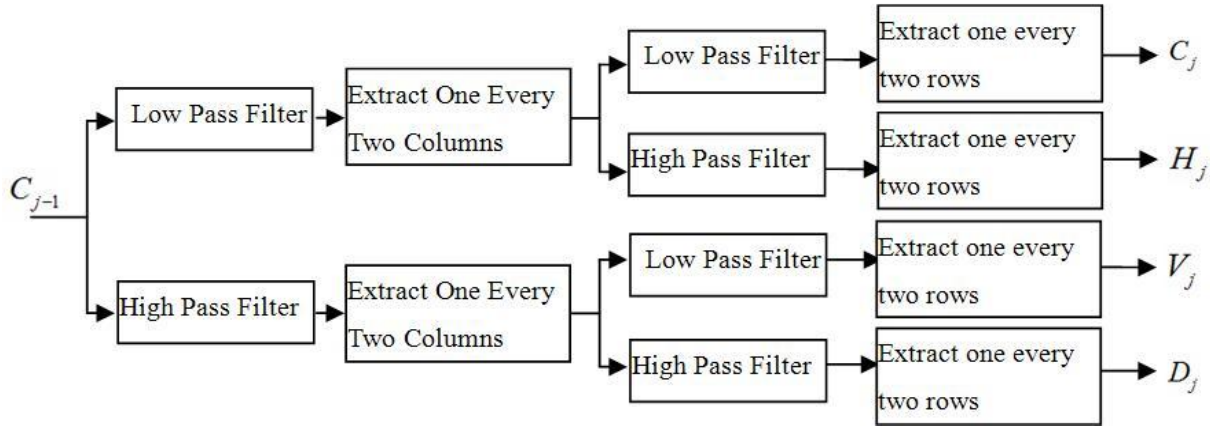

Figure 2. Mallat decomposing flowchart.

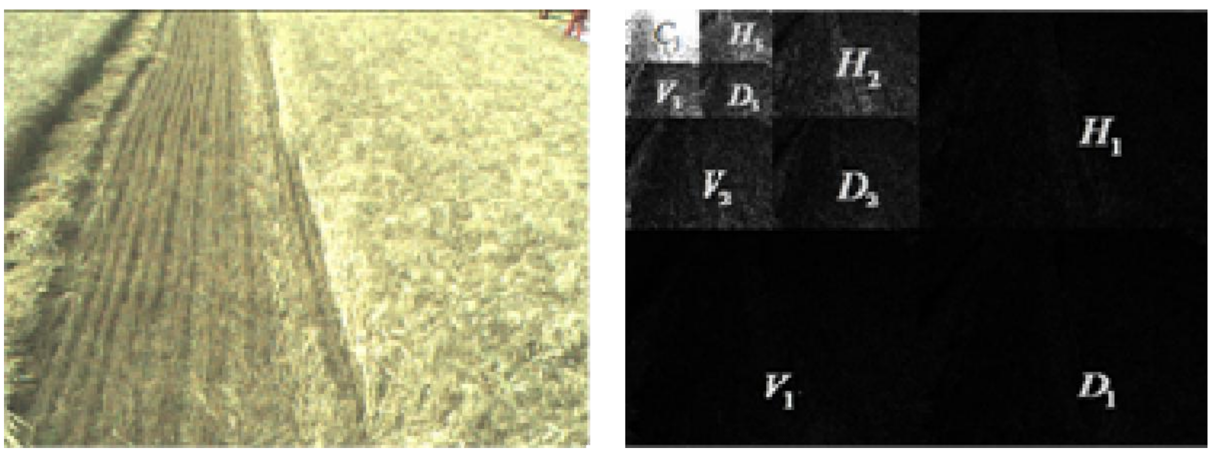

Figure 3. Mature wheat image and its three time wavelet transform.

4. Locate the extremum position and get the result.

Wavelet transform of mature wheat gray image

The camera grabbed the mature wheat color image. Before entering the algorithm, the color image should be converted to gray image by using Equation 1:

$$Gray = 0.229 \cdot r + 0.587 \cdot g + 0.114 \cdot b \quad (1)$$

Through this processing, the cut/uncut edge is just represented only by the different grey values, and it can partly eliminate the effect of different luminance. At the same time it can reduce the dependence on color image and decrease processing complexity. By observing the mature wheat gray image, we could find that there was much noise information produced by cut wheat stubbles and massed individual plants texture. In image frequency domain, the cut/uncut edge belongs to the outline contour and consists of low frequency area, and using general segmentation or low pass filter could not get the needed effect. For the intrinsic characteristics of multiscale and multiresolution, 2D wavelet transform has been widely used in the image processing. Selecting sym4 as the wavelet function and actualizing Mallat decomposing the gray image form 1 layer to L layer, we get decomposing flow chart in Figure 2.

Here, in every scale, C_{j-1} includes the former most low frequency information, and through wavelet transform C_J includes the most low frequency information at j scale. H_j includes the most horizontal detail, V_j includes the most vertical detail, and D_j includes the most diagonal detail.

In the frontage of combine harvester, the difference of color and brightness between mature wheat ears and mature wheat haulms was obscure. In comparison with fragment edges produced by noise information, the cut and uncut edge belongs to outline contour. By wavelet transform, most outline contours were distributed in the large scale and low frequency area C_j. On the contrary, most fragment edges were distributed in other different scales and high frequency area such as H_j, V_j and D_j. Too much large scale of wavelet transform would bring on the low location precision, and too small would induce dissatisfied effect of eliminating fragment edges. After many tests to select the scale of wavelet transform, 2^3 was the best scale for the processing result, and the low frequency area C_3 is the next rotation transform target. Figure 3 shows the wavelet transform result at 2^3 scale.

After wavelet transform, the size of wavelet image C_3 became $1/2^3$ times of original image, but it contained most outline contour. Also, it could reduce time in the after processing. On the other hand, the size affects the cut and uncut edge's position but not

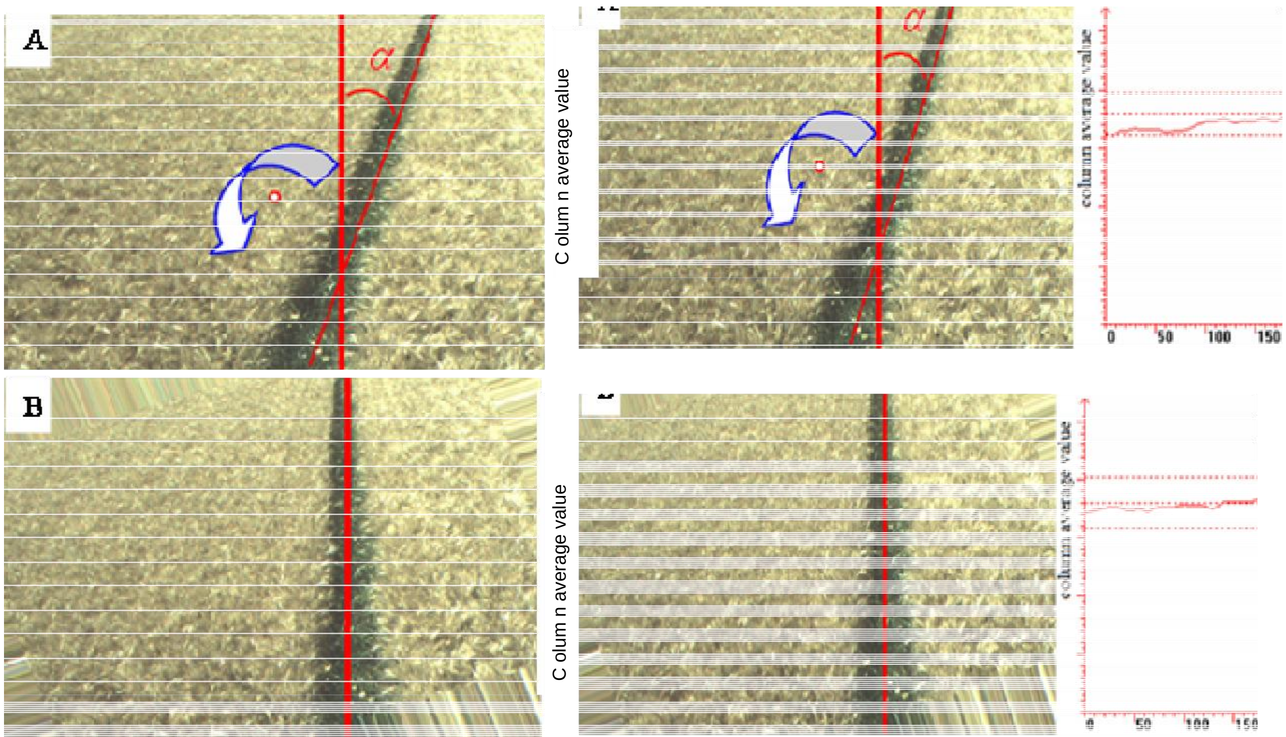

Figure 4. The column average values comparison between rotation and un-rotation transform image, (A) Mature wheat raw image and its curve of column average values, (B) The image after rotation transform and its curve of column average values.

the angle. According to the scale relationship, the change of the position is also $1/2^3$ times of original position.

Wavelet image rotation transform

Image rotation transform is defined as the image coordinate systems transform, depending on Equation 2:

$$U = u\cos\alpha + v\sin\alpha + u_0$$

$$V = -u\sin\alpha + v\cos\alpha + v_0 \qquad (2)$$

Here, (u, v) is the initial image coordinate, (u_0, v_0) is the center. (U, V) is the rotated image coordinate, its center is the initial image left-bottom point. α is the rotation angle and its positive value represents the anticlockwise rotation direction. It must be clear that (u_0, v_0) should be the center of imaging plane in the ideal situation of camera imaging pinhole model, but in fact, for the reason of various distortions produced by manufacturers, lens installation error is deviated at the center. By using Zhang et al. (2000), camera calibration of the intrinsic camera parameters could be obtained:

$$(u_0, v_0) = (363, 259), f_x = 868.77, f_y = 867.29$$

Where, f_x, f_y are the effective focus lengths of each X_c, Y_c.

In mature wheat image, regarding the cut/uncut edge as one line, we could get the result that the angle between the line and the vertical line is in the range of ±30°, "+" representing the angle of deviation to right, and "-" to left. Now let's assume that the angle names heading angle α, and the image is rotated anticlockwise with angle α; meanwhile, if α is a negative value, the rotation direction is clockwise. After this processing, the cut/uncut line is vertical and the new heading angle is zero. During every rotation transform, the image's column average values are calculated, and we can find that when heading angle is zero in the column average value curve, the position of cut/uncut line will be a break change point. Figure 4 presents the effect. So through the extremum value of all column average values' difference, the heading angle and position can be located. But in fact, the heading angle α in the range of ±30° is not known, so the way of angle enumeration is selected.

For one N x W (N is the number of rows, W is the number of columns) wavelet image, the change of enumeration angle α is 60°, and all enumeration angles compose one arithmetical sequence, and the common difference Δα is determined by the rotation transform times t. Equation 3 presents the relationship:

$$t = \frac{60}{\alpha} \qquad (3)$$

Structure the rotation and projection matrix and its difference matrix

For every rotation transform, the all column average values (just one vector) was calculated. Gathering all vectors, the rotation and projection matrix R is structured. R's number of rows is equal to the rotation transformation times *t*, the number of columns is the wavelet image's width *W*.

The less time of one frame processing is very important to improve the system real-time performance. We know that one frame processing time includes four steps mentioned above, and the most is spent on the rotation transform. According to the rotation transform principle, the rotation transform processing time is

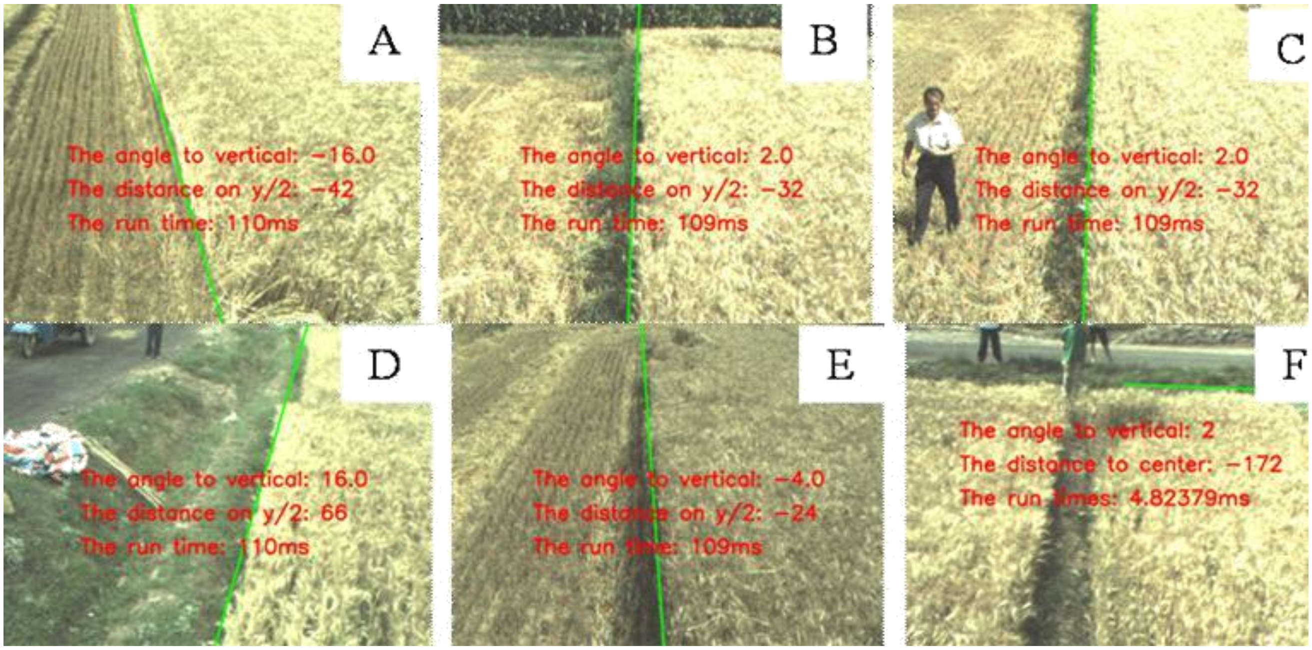

Figure 5. The cut/uncut edge line detection results of several typical cases, (A) facing sun, (B) back to sun, (C) disturbed by human, (D) disturbed by other color, (E) in cloud, (F) field end line detection.

irrelative to the enumeration angle; this is to say that the one frame processing time is mainly determined by rotation transform times. So the rough-division and elaborate-division was selected to reduce rotation transform time. Rough-division means selected the bigger common difference $\Delta\alpha$, and elaborate-division means the smaller.

Through rough-division, the heading angle α can be obtained roughly, and elaborate-division can get more accurate heading angle based on the rough angle. The importance is that, initializing the elaborate-division common difference as 1°, the change of elaborate-division enumeration angle is two times of rough-division common difference, not like the former 60°. In this way, the total rotation transform times t can be expressed by Equation 4:

$$t = \frac{60}{\alpha} + \frac{2\alpha}{1} \qquad (4)$$

Apparently, t has the minimum $t_{min} = 2\sqrt{120} \approx 22$ when $\Delta\alpha = \sqrt{30}$, this is to say that the way of two step rotation transform has lesser rotation transforming times than using one step rotation transform at 1° of common difference. This gives us the guidance that 5° initial common difference and 1° final common difference is the best match and can get the least rotation transform times.

Locate the extremum position and get the result

In order to find the heading angle and position in R, difference operation was selected just like Equation 5:

$$dst(n,w) = |R(n,w+1) - R(n,w-1)| \qquad (5)$$

Where R(n, w) is R's n row and w column value, dst(n, w) is R_d's n row and w column value and R_d is named difference rotation and projection matrix. Through the position of R_d's extremum, the heading angle and lateral position can be obtained. When there are more the same extremum, the nearest former frame result is selected.

RESULTS AND DISCUSSION

Using VC++6.0 and the upper algorithm, the software of recognition cut/uncut edge line was developed. According to the algorithm description and 800 images testing results, the following characteristics could be drawn out.

Anti-color-disturbance

The algorithm converted the color image into gray image and the color information was eliminated partly. Through wavelet transform, the low frequency information remained and after rotation transform, the projection operation based on all columns was carried out. This is to say that one pixel or one region disturbance with the color or gray differing from the cut/uncut edge gray had little impact on the matrix R, and did not change the detection result. Figures 5c and d are that cases, but in Figure 6, using SLHT method, the lots of error candidate points changed the detection result, despite its processing time was shorter.

Independent on the whole brightness

Essentially, the algorithm used statistics method, not using image segmentation, global threshold value, etc.

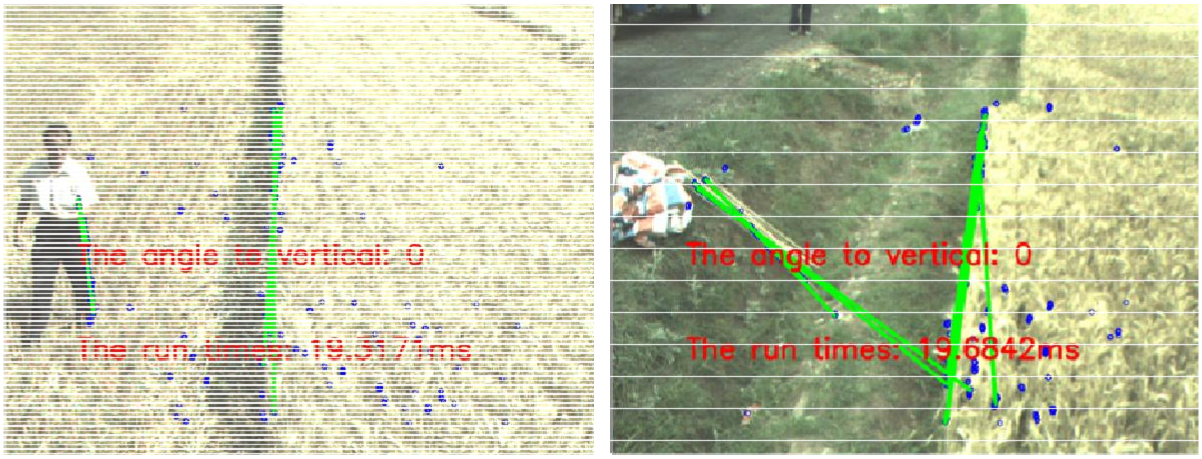

Figure 6. The detection results using SLHT method.

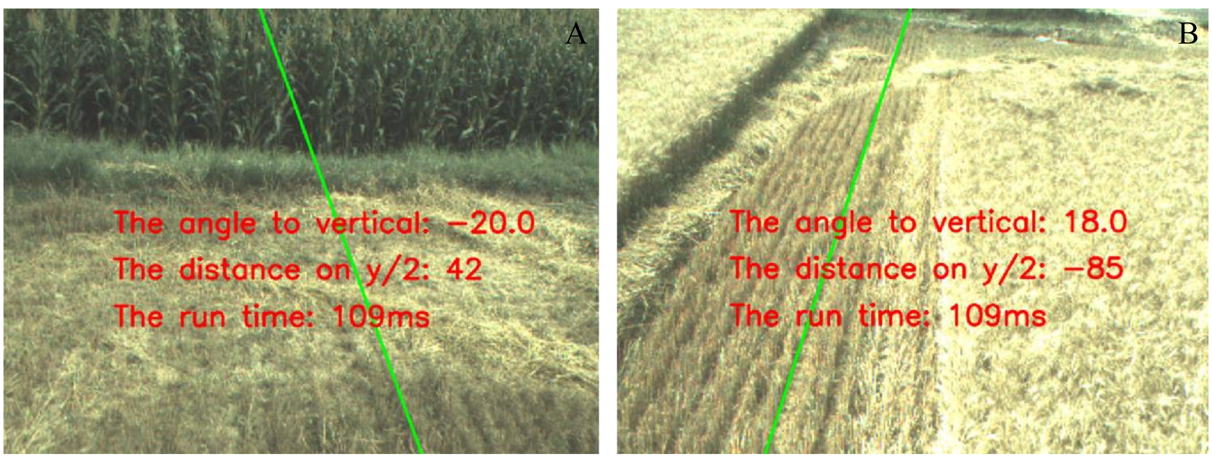

Figure 7. The failed detection, (A) no visible edge line, (B) influenced by cut wheat stubbles.

and if the cut/uncut edge line really existed in mature wheat image, despite the whole brightness was low, like Figure 5e, or high like Figures 5a, b and c, the algorithm could get the exact line.

High robustness

The algorithm was based on the line mode, if only there was break change matrix R, the extremum position would be found out. The break change would produce when the edge line of outline really existed. From this point, the algorithm could be also used to detect various crop lines, ridge rows, plow gutter lines and the marker lines between worked and un-worked area.

Eight hundred images (in different weather, sunshine and cloud, disturbed by human and other objects such as telegraph pole as sown in Figure 5d) were acquired when combine harvester was working under manual control, and the sample rate was 1Hz. Using the upper algorithm and setting rough common difference 5°, final common difference 1°, the accuracy rate of recognizing cut/uncut edge line achieved 95.6%, and the average processing time was 109.3 ms per frame and standard deviation was 1.33 ms. The failed detection mainly came from the cases of Figure 7. The failed detection possessing 4.4% mainly produced by two cases: no visible edge line and other potential edge line acting as disturbance. For the first case, just like combine harvester moving to the end of the field, there was no edge line in front of combine harvester; however, the algorithm give one result just like Figure 7a. So one appropriate threshold δ_R was given to determine the validity of current detected edge line. If R_d's extremum was bigger than δ_R, the current detected edge line was valid. If smaller, invalid. In this project, the perfect value of δ_R is 40. For the second case, the position of R_d's maximum was not the mapping parameters of cut/uncut edge line. However, using the second and third extremum of R_d's, there were three candidate cut/uncut edge lines. The minimal distance of three current extremums to the former frame extremum in R_d was selected to get the current cut/uncut edge line. In this project, the precision of heading angle was 1°; however, in some other application, this precision might not satisfy the system requirement. If the system required 0.1° precision, using the method rough-division and elaborate-division mentioned above, the following could be obtained:

$$t = \frac{60}{\alpha} + \frac{2*10*\alpha}{1} \geq 2\sqrt{1200} \approx 69$$

When $\Delta\alpha = \sqrt{3}$ t got to minimum. It was not the optimization. Based on the two common differences of 5° and 1°, 0.1° was selected as the third common difference, and we could get the lesser rotation transfor-ming times $t = 22 + 20 = 42$. Theoretically speaking, the more times the division was, the lesser the rotation transforming times was, just like the following expression:

Two divisions: $$t = \frac{60}{\alpha} + \frac{2\alpha}{0.1} \geq 2\sqrt{1200} \approx 69$$

Three divisions: $$t = \frac{60}{\alpha_1} + \frac{2\alpha_1}{\alpha_2} + \frac{2\alpha_2}{0.1} \geq 3\sqrt[3]{2400} \approx 40$$

Four divisions: $$t = \frac{60}{\alpha_1} + \frac{2\alpha_1}{\alpha_2} + \frac{2\alpha_2}{\alpha_3} + \frac{2\alpha_3}{0.1} \geq 4\sqrt[4]{4800} \approx 33$$

On the other hand, more divisions would lead to the more matrixes R and R_d which would bring more time spending. To make the algorithm work better, $\Delta\alpha_1 \leq 5°$should be satisfied. If $\Delta\alpha_1$ was too big, the extremum of matrix R_d was not distinct. With minor adjustment, the algorithm can be used to detect the field end line which is important to the swerve of combine harvester. Generally speaking, the field end line trends to horizontal line, not like the cut/uncut edge line trending to vertical. After wavelet and rotation transform, the all vectors of row average values compose the matrix R, and through R_d's extremum, the field end line can be obtained. Figure 6f is the result at the case of setting ROI (region of interest).

In order to improve the real-time performance further, using the former frame information including heading angle and lateral position is a very effective means. According to the former frame information, the appro-priate ROI can be set, and the range of rotation angle shrinks. All these means can reduce the processing time. The next step is to improve the performance of detecting multi-edge lines and to reduce the dithering.

Conclusion

Agricultural vehicle guidance offers the potential to reduce operator fatigue, improve field efficiency and allow high accuracy over extended period of time. A novel algorithm was put forward to detect the mature wheat cut/uncut edge line. The wavelet image rotation and projection algorithm include four steps: wavelet transform of mature wheat gray image, wavelet image rotation transform, structuring the rotation and projection matrix and its difference matrix, and locating the extremum position and getting the result. Tests showed that the algorithm has the characteristics of anti-color-distur-bance, independent on the whole brightness and high robustness. The means of improving real-time per-formance and its extension were discussed and also the future research direction was pointed out.

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