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Agricultural Robot Turning in the Headland of Corn Fields

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Abstract. This article discusses the development of variable field of view (FOV) of camera to realize headland turning of an agricultural robot in corn fields. The variable FOV of camera was implemented to change direction of view of camera by two DC motors rotating separately in vertical and horizontal planes. Headland turning is executed in six steps: end of row detection and guidance, going blind for a distance, first 90˚ turning, position calculation, backing control, second 90˚ turning. Mathematically morphological operations were chosen to segment crops, and fuzzy logic control was applied to guide the robot. Three repetition tests were conducted to perform the headland turning. A maximum error of 17.4mm when using the lateral view and good headland turning operation were observed. It was successful for variable FOV to implement headland turning of the agricultural robot in corn fields.

1. Introduction

Since agricultural vehicle navigation based on machine vision was first proposed, methods based on machine vision have been studied extensively in agricultural vehicles. For example, such systems have been applied to guide vehicle for spraying, weeding, cultivating and harvesting [1-4]. In addition, many agricultural robots with machine vision performed well in fields [5-7]. These studies have proven applicability of machine vision in agricultural vehicle guidance. However, fewer authors implemented headland turning operation in the end of crop row by only using machine vision so far.

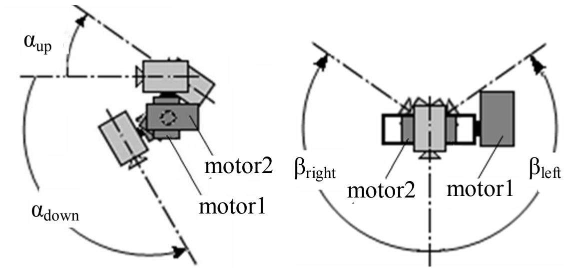
The objective of this work is to implement headland turning of an autonomous agricultural robot with variable FOV of machine vision achieved by changing the direction of view of camera. During headland turning operation, the camera's direction of view was changed to determine position of the robot in order to complete headland turning operation of the robot into the next rows.

2. Materials and Methods

2.1 Concept of variable FOV of camera. A settled FOV has been always used in autonomous vehicles for field applications so far. But it cannot supply sufficient visual information for guidance and other field operations. In this work, two DC motors were used to implement a changeable FOV of camera, as shown in Figure 1, where motor 1 and motor 2 controls camera rotation in the vertical plane along the forward direction of vehicle and in the horizontal plane paralleling to the ground, respectively.

In the vertical plane (Fig. 1(a)), elevation and depression angle of camera are defined as α_{up} and α_{down} when camera is looking up and down respectively. In the horizontal plane (Fig. 1(b)), rotation angles of camera to the left and the right are defined as β_{left} and β_{right}, respectively.

This camera not only has continuously changeable angle in the vertical plane, which can change FOV of camera in front of robot, but also can observe crops according to a lateral FOV which means that the direction of camera is biased to the left or the right.



(a) (b)

Fig. 1. Schematic diagrams of variable FOV

Fig. 2. Robot platform

2.2 Experimental equipments. AgTracker was selected as robot platform for this study (Fig. 2). The basic guidance ability was implemented by a microcontroller. This involved controlling speeds of two motors and receiving steering information from a laptop, which is relayed to drive the motors in PWM form with skid steering. A QuickCam was chosen as visual device and connected to the laptop through USB 2.0 cable. Matlab image acquisition and processing software were mainly applied to acquire and process images. Then, the laptop sent commands to a microcontroller in the robot and thus the motor controller received PWM signals to drive the motors. RTK GPS receiver was equipped to record running data of this robot.

2.3 Headland turning. Algorithm of headland turning operation is shown in Fig. 3, which can be divided into 6 steps: ①End of row detection and guidance. The robot firstly detects crops near the end of row and guides the robot before headland turning with a lateral FOV of camera. When there is no crop in image, it indicates that the robot reaches the end of crop rows. ②Going blind for a distance. The robot continues moving forward with current heading for a distance without image acquisition and processing. ③First 90˚ turn. Given that the robot turn left into the next row in this work. Speed of left and right wheels and turning time were determined through indoor tests and field trials in sequence to achieve 90˚ turn to left, due to no direction sensor. ④Position calculation. Then the robot stops and rotates the camera into the direction perpendicular to longitudinal direction in the horizontal plane to observe the left crop rows, thus to calculate its position. ⑤Backing control. This operation depends on the inter-rows distance in corn field and the size of the tested robot. Based on the step ④, the backing distance and speeds of left and right wheels will be calculated. ⑥Second 90˚ turn. The robot turns 90˚ to left again with a certain turning time. The similar operation was realized between this step and the step ③ except the different turning time.

2.4 Image segmentation. In this work, the lateral FOV of camera (Fig. 4(a)) was chosen to detect crops near the end of rows, although only several corn stems were contained in image (Fig. 4(b)). Mathematically morphological operations with specific structure element were adopted to identify and segment corn stems (Fig. 4(c)). The guidance line was shown in Fig. 4(d).

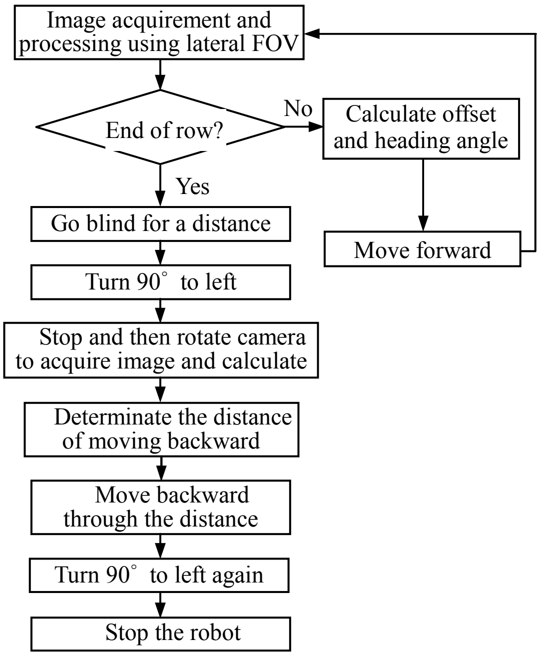


Fig. 3. Headland turning algorithm

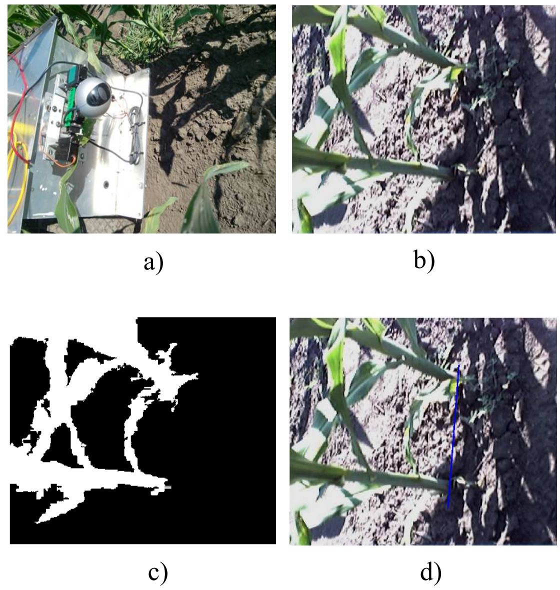


Fig. 4. Machine vision results of lateral FOV

A far FOV of camera was chosen to determine position and direction of the robot, which further determines how to make the robot back. The simulated experiments were implemented in advance to decide position of robot relative to the crop rows (see Fig. 5, where three black tapes represent three actual corn rows). After the robot firstly turned 90˚, the camera angle was changed to observe the third corn row. The different position of the robot relative to the simulated/crop rows were acquired to find out correspondence relationship between the actual position of the robot relative to the crop rows and the crop rows position in images.

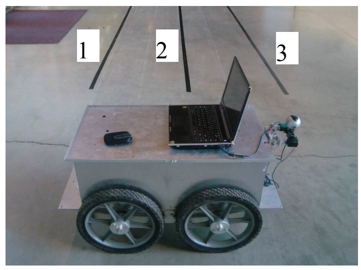


Fig. 5. Simulation of Far FOV

2.4 Headland turning control. During the end-of-row guidance, the robot moved forward by adjusting wheels speeds in the light of guidance information. Then the robot was controlled to go blind a distance with its previous direction. But for the two 90˚ turning control, it was implemented by controlling wheels speeds and the turning times. As for the backing control, position information (the robot's distance away from the referred crops row and the direction relative to the referred row) were used to calculate backing distance and speeds of wheels.

The speed difference of left and right wheels was controlled according to the difference of PWM signals. Fuzzy control with two inputs (offset and heading angle of the robot) and one output (PWM difference) was adopted to realize the control. The detail about the fuzzy control is illustrated in [7].

3. Experimental procedures

To verify performances of the designed system, tests were conducted in corn fields of University of Illinois. Corn were planted in rows with about 750mm inter-row distance and about 150mm intra-row distance, the height of corn was about 700mm during the tests. And the robot ran between two corn rows. In addition, the initial speed of robot was set to 0.2 m/s, backing speed 0.1 m/s. Left and right wheels speeds were fixed to 0.01 m/s and 0.2 m/s during two 90˚ turn. And the starting point of the tests was 2 m away from the end of corn rows. The tests were repeated for 3 times with the same starting point. Once positioned, the robot started under autonomous control and stopped automatically.

GPS data were analyzed to evaluate performance of headland turning. The maximum error, average error, RMS error and standard deviation were calculated to evaluate guidance accuracy during the end of row guidance. Some position points, such as the points after first 90˚ turn, the points after second 90˚ turn, the farthest point in robot trajectory and the backing distance, were recorded to reflect the turning performances. The effect of going blind on headland turning was analyzed by comparing the positions of end point and the farthest point during the first 90˚ turn and observing the turning trajectory of the robot. Additionally, the performance of backing control was evaluated by measuring the backing distance and observing the backing trajectory. And the performance of the second 90˚ turn was judged by measuring the position of end point and observing its trajectory.

4. Results and discussion

Fig. 6 shows one trajectory of headland turning in three repetitions.And the performance measures are shown in Table 1 and Table 2, respectively. It should be noted that, the "-" sign in Table 1 indicates that the error is biased to the right, and X and Y in Table 2 represent positions coordinates in the directions parallel and perpendicular to crop rows, respectively. During the end of row guidance, the maximum error was less than 17.4 mm for three repetitions (in Table 1). And the performances of end of row guidance were similar for three repetitions. The RMS error with 49.3mm in third test shows a good control performance for the robot. The lateral FOV guidance performed well in corn fields. According to the data in Table 2, the main difference appeared in Y direction. The offsets in Y direction were 23.6 mm and 20.2 mm at the positions after first 90˚ turn and at farthest point, respectively. The offset of backing distance was no more than 16.7 mm, and the backing control strived to make the robot perpendicular to corn rows parallel to the rows when the backing control was end, though the robot is not perpendicular to the corn rows at the starting position of backing stage. These show good performance of backing control based on the far FOV. The 14.8 mm maximum deviation from the center line in the second test indicates that the control algorithm can make the robot locate near the central line of the next corn rows with high accuracy.

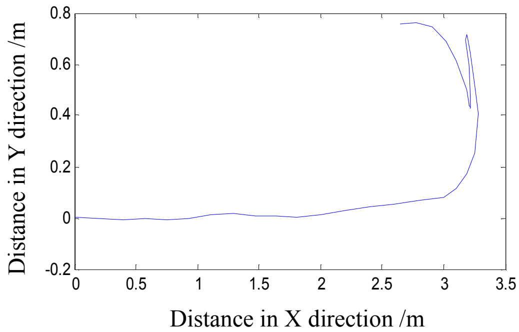


Fig. 6. Robot trajectory

Table 1. Performance of the lateral FOV guidance and going blind stages (Unit: mm)

	Maximum error	Average error	RMS error	Standard deviation
I	15.4	-12.7	49.3	8.1
II	16.1	-12.4	36.7	12.3
III	17.4	3.0	28.4	8.0

Table 2. Performance of the whole process

		I	II	III
Position after first 90°	X (mm)	3183.6	3182.3	3182.9
	Y (mm)	693.2	698.1	716.8
Position after second 90°	X (mm)	2611.1	2675.0	2643.0
	Y (mm)	740.4	738.2	757.0
Position at farthest point	X (mm)	3282.5	3281.4	3302.0
	Y (mm)	427.8	408.8	407.6
Backing distance (mm)		303.4	287.9	286.7

5. Conclusions

Variable FOV of machine vision was developed to execute headland turning operation for an agricultural robot in corn fields. Three repetition experiments were conducted at the same starting point with the same starting speed. Lateral FOV machine vision showed acceptable performance in the end-of-row detection and guidance. The average errors were no more than 12.7 mm in most cases. The maximum error was not more than 17.4 mm in any test run. The turning process performed well, especially the far FOV of camera, which was applied before backing control, ensured the completion of headland turning operation. These experiments demonstrated the accuracy of the guidance system and headland turning control system and successful operation of the robot in corn fields. However, the farther tests will be performed to verify the application of variable FOV of machine vision.

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