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RESEARCH ON VISUAL NAVIGATION AND REMOTE MONITORING TECHNOLOGY OF AGRICULTURAL ROBOT

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Abstract- To solve the problems of instability of agricultural robot when avoiding obstacles, a kind of navigation method which combined monocular visual navigation technology and remote monitoring technology was proposed: using the centerline method to extract the navigation path to achieve visual navigation; the monitoring center received two-way real-time image signals of the agricultural robot, when the agricultural robot met the obstacle or other situations, the remote monitoring center would start the alarm, then the operators could send control signals through the monitoring software to implement manual intervention. The experiment showed that the system improved the reliability of the navigation.

Index terms: agricultural robot, visual, navigation, remote monitoring, reliability.

I. INTRODUCTION

Since China's cultivated area is vast, the application of agricultural robots is essential and has improved the labor efficiency greatly. However, poor reliability of traditional agricultural robots in autonomous navigation when encountering the obstacles or cliffs is an existing problem. So, developing a new agricultural robot which has the functions of both visual navigation and remote monitoring becomes quite meaningful.

There are many researches on the visual navigation technology of the agricultural robot, but most of them focused on the extraction of the paths and the navigation parameters. In 1996, Japan University of Kyoto developed a vision-based navigation pesticide spraying robot which can real-time identify the crop row as the navigation path, move and work based on the navigation path [1]. The British Silsoe center studied extraction method of navigation information. The main idea is that the relationship between the geometric characteristics of row crops and the camera, using Hough transform to detect crop rows as the agricultural robot navigation path and use certain methods to obtain navigation parameters to guide the movement of agricultural robot, After the test verification, lateral error only 18 mm [2], but this was merely in the theoretical and experimental stage, and did not get the promotion. In 1998, autonomous navigation agricultural robot developed at the University of Illinois, USA, can already trace a curve at a speed of 10 Km / h in the experiment, also can track a line designated in advance at a speed of 17 Km / h, which lay the foundation for later visual navigation research[3]. S.I.Cho et al [4] designed an intelligent tractor system, using methods of counting the histogram in the vertical direction to detect the navigation path during visual navigation, and then combined the result of the detection and the fuzzy control technique to achieve a tractor visual navigation control. ARGO autonomous vehicles developed by the Italy University of Parma, used stereo vision to detect obstacles and real-time detecting and tracking navigation path, in 2000 km long distances, 94% of the distance is from the autonomous navigation in the experiment in 1998, the average speed was 90 km and a top speed of up to 123 km [5]. T.Sasaki developed a mobile robot indoor navigation system, the route image collected by the CCD camera is analyzed to get the traveling path, mobile robot moved in accordance with the real-time path drawn [6]. J.A.H.Ortiz presented the application of a new multi-objective evolutionary algorithm called RankMOEA to determine the optimal parameters of an artificial potential field for autonomous navigation of a mobile robot. The performance of RankMOEA was compared with NSGA-II and SPEA2, RankMOEA clearly outperformed NSGA-II and SPEA2 [7]. Yang Weimin used the image processing algorithm based on the Hough transform and the dynamic window technology to extract the navigation features of natural environment [8]. Gao Feng and some others used the method of Surface-Belt model matching visual identification based on genetic algorithms, directly identified field crop images without any pretreatment which obtained good effect in the real-time control [9]. An Qiu used the shadow remove method based on the light independent graph, had significant meanings in navigation parameter extraction of complex environments [10]. F.Yang, S.Liu and some others developed Camera calibration , image acquisition , stereo rectification , stereo match and depth calculation to research a detection method of various obstacles in farmland by using the methods such as Bouguet algorithm, area match , triangulation and so on. The experiment showed that the accuracy rate of the obstacle detection reached 96% [11].

However, relying solely on visual navigation technology to realize autonomous navigation of the agriculture robot in the complex farmland environment does not take the factors of the obstacle avoidance and the cliff avoidance into consideration. Therefore it is relatively unreliable. In this case, this paper proposed the idea of combining the visual navigation and the remote monitoring technology to realize navigation. The designed system was installed in agricultural robot and its feasibility has been verified with experiments. The structure of the paper is as follows. Section I gives a general introduction to robot visual navigation research status and the main content of the article. Section II describes the system composition and working principle. Section III analyzes the research of visual navigation. In Section IV, remote monitoring technology research is presented, the effect of which is verified by experimental results in Section V. Finally, conclusions are given in Section VI.

II. SYSTEM COMPOSITION AND WORKING PRINCIPLE

The system is composed of visual navigation subsystem and remote monitoring subsystem functionally, and the upper and lower bit machine structurally. As shown in Figure 1 below: the slave computer is agricultural robot, including control signal receiving and processing devices, hydraulic drive device, video signal acquisition and wireless transmission devices; the host computer is monitoring center terminal, including monitoring processor, video signal radio receiving apparatus, control signal wireless transmission apparatus and man-machine interface.

System working principle : The slave computer of agricultural robot collects the road condition information in front of the machine with two CCD cameras and sends image signal to the host computer monitoring center through wireless local area network(LAN) established by the front-end and back-end wireless bridge, and then the monitor in the monitoring center displays the real-time dynamic two-way image signals and processes one way of the image signals to get navigation parameters which visual navigation requires. According to the navigation parameters, the system determines the relative position of the agricultural robot and automatically sends control signals to control agricultural robot walking (forward, turn left, turn right, stop) to achieve the purpose of tracking the navigation path. If there is an obstacle or a cliff in the front, the robot will send fault information to the monitoring center automatically and suspend the movement of the agricultural robot. After receiving fault signal, monitoring client will start alarm module (horn) to alert the user. The user then can send control commands to the agricultural robot through remote monitoring subsystem with the man-machine interface. According to its working principle, we can say that the visual navigation subsystem and the remote monitoring subsystem are working coordinately. As the auxiliary system of visual navigation subsystem, the remote monitoring subsystem will greatly improve the safety and the reliability of the agricultural robot.

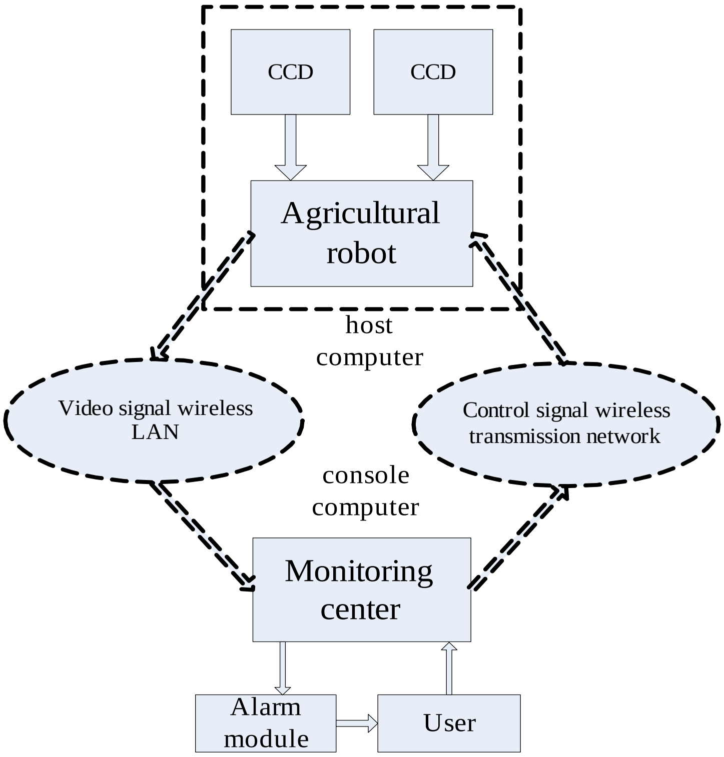


Fig.1. Constitute diagram of overall system

III. VISUAL NAVIGATION SUBSYSTEM

Visual navigation technology is the key technology in robot intelligent navigation field, which can reduce the navigation cost and collect images with rich-information. Useful navigation information can be got by using rational image processing methods, so image processing algorithms should be improved continuously to furthest extract useful information [12]. In this paper, visual navigation subsystem gets navigation path through processing real-time environment image captured by monocular camera. Two cameras are installed on the robot and collect two-way image signals. Then the image signals are transmitted to the monitoring computer in monitoring center in real time via a wireless LAN. The monitoring computer carried out the operations, such as, image preprocessing, calculating navigation path etc. to finally determine the relative position of the robot, which lay a foundation for the realization of vision navigation.

a. Monocular camera calibration

Using a monocular camera for visual navigation, the camera must be calibrated for the purpose of finding the camera's internal and external parameters. Then, we can establish the relationship between the images coordinates and the world coordinates, providing a basis for the follow-up visual navigation.

The system selects "Tisa Two step" to calibrate camera. Because of the consideration of the radial distortion of the camera, the accuracy is high [13]. The First step is to use the method of the least squares to solve the over-determined linear equations to obtain all external parameters. The second step is to recursively use nonlinear optimization method to obtain internal parameters. The external camera parameters got by "Tisa two-step method" are shown in Table 1, the relationship between the images coordinates and the world coordinates is established.

Table 1: Results of camera calibration

Results of camera calibration				
Camera external parameters	Rotation matrix R	r_1=1	r_2=0.0071	r_3= -0.0018
		r_4=0.0056	r_5= -0.5717	r_6= 0.8205
		r_7=0.0048	r_8= -0.8205	r_9= 0.5717
	Translation vector T	T_x=-844.6	T_y=209.7	T_z=5873
Camera	$(u_{0,}v_0)$	(176, 144)		

intrinsic parameters	f	24.2155
	k_1	0.0508

Corner detection error is analyzed, as is shown in Figure 2, the various color points are the detection point, if the detection point is at coordinate (0,0) (error is zero), proving the best results, most corner coordinates have a small deviation with the true value, so the experimental results are reliable.

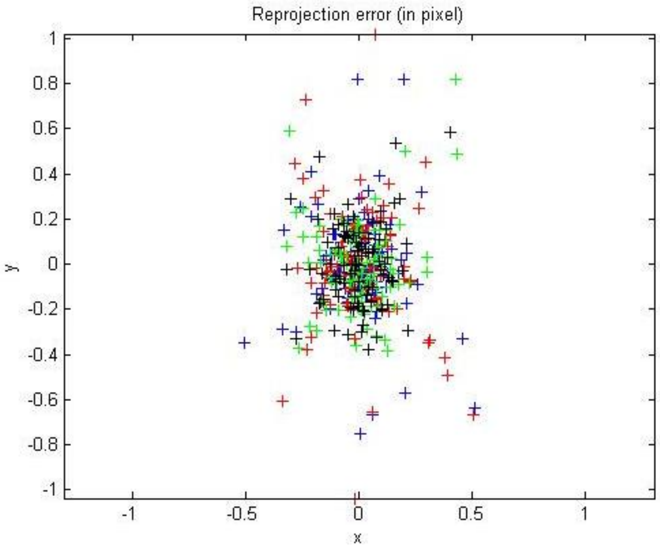


Fig. 2. The error analysis diagram of corner detection

According to the calibration results of monocular camera, a comparison was made between calculated values and actual values of a set of measured points image coordinates, the results are shown in Table 2, the comparison results proved that the error in the range of 5 pixels error range, therefore, the results of calibration can be used for monocular visual navigation and had high precision.

Table 2: Comparative table of experiment coordinate and real coordinate

The checkpoint World coordinates	**The calculated image coordinates**	**The actual image coordinates**
$(x_w, y_w, z_w)mm$	$(X', Y')pixel$	$(X, Y)pixel$
(826，429，0)	(171.00，125.40)	(170.91，125.38)
(826，369，0)	(170.91，145.99)	(170.80，146.14)
(826，309，0)	(170.82，166.20)	(170.77，166.23)

(726，429，0)	(151.87，125.30)	(151.61，125.34)
(726，369，0)	(151.92，145.78)	(151.64，145.99)
(726，309，0)	(152.03，165.89)	(151.95，165.96)
(706，429，0)	(133.23，125.33)	(132.64，125.16)
(706，369，0)	(133.43，145.56)	(132.77，145.60)
(706，309，0)	(133.71，165.44)	(133.19，165.62)
(646，429，0)	(115.46，125.48)	(113.85，125.10)
(646，369，0)	(115.77，145.34)	(114.26，145.54)
(646，309，0)	(116.22，164.87)	(114.69，165.29)
(586，429，0)	(98.84，125.75)	(95.48，125.26)
(586，369，0)	(99.26，145.12)	(96.13，145.19)
(586，309，0)	(99.83，164.18)	(96.57，165.34)

b. Image preprocessing and navigation path extraction

To achieve automatic visual navigation, agricultural robots must detect front road condition information in real-time, then determine navigation path [14]. So, navigation path extraction is critical. When working, robots firstly walk on the roads until reach the farmland, so the navigation path extraction should be carried out on two levels-- the road environment and the farmland environment. The system first processes dynamic road image and extracts path in real time, then farmland environment image.

b.i Road image preprocessing and navigation path extraction

To obtain the navigation path, first, images captured must be preprocessed [15]. This process includes the gradation processing, the filtering processing, the binarization processing [16], the expansion, the etching treatment, et al. The process as shown in Figure 3 was used in the paper for the road image. A lot of processing operations of the whole image will inevitably affect the real-time performance. In this paper, processing was limited to a particular region - the region of interests (ROI), because useful information for identifying the edges of the road was only a small section of the whole image. The selection of the region was determined by taking a large number of experiments, and selecting the dynamic image feature, Figure 3 (b ~ g) is the results of pretreatment effect of static image, through a series of preprocessing to the "ROI" of the original road image, the edge of the road can be basically clearly discriminated, and the real-time performance was greatly improved.

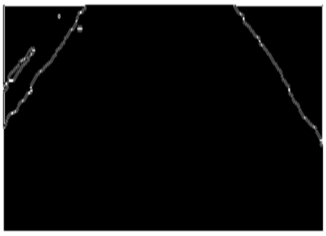
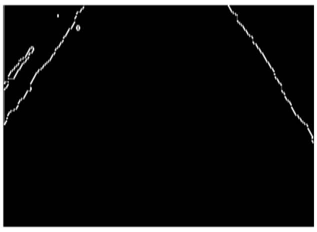
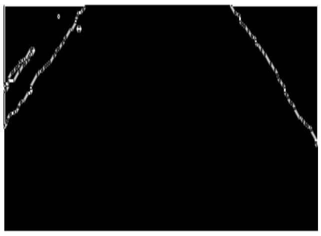
(a) Image preprocessing process

(b) original image of roads (c) graying (d) median filter

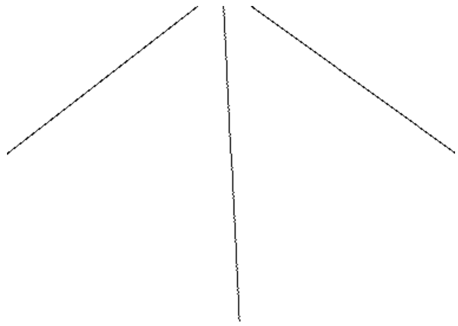
(e) binarization (f) expansion (g) corrosion

Fig.3. Preprocessing image of road image

Road edge extraction can be carried out after pretreatment of the road image. A basic method is the differential operator detection which has good effect. In this paper, three kinds of differential operators were adopt to detect image edges [17]. Figure 4 (a ~ c) are the edge schematic diagrams after detection. It can be seen that three kinds of differential operators has similar effect in detecting the edge of the simple road image, therefore, in the practical application, we can take any kind of differential operator to detect the edge of the road.

(a) Sobel (b) Roberts (c) Prewitt

(d) Road image pixel after inverse transform (e) Transform and fitting the edges of the road and navigation path

Fig.4. Schematic diagram of extracting road edge and navigation path

Road edge lines of the road can be fitted after extracting, the general methods are the least squares and the Hough transform [18], Hough transform method is used in this paper, Figure 4 (d) is the schematic diagram of pixel inverse transform after the edge extraction, Figure 4 (e) is the schematic diagram of navigation path extracted by using centerline method after Hough transform method fitting the edge line. The center line in figure 4 (e) is the navigation path extracted, the algorithm for extracting center line is scanning pixel points of each row, when the gray value being 0, remembering its pixel coordinates, then taking the average of the abscissa of the two coordinates, obtaining new coordinates, setting the gray value of the new coordinates to 0, then the navigation path can be obtained.

b.ii Navigation path extraction of Farmland environment image

Based on the study of road images, we analysis farmland image, the pretreatment process is the same to the road image, farmland environment image preprocessing results are shown in Figure 5 (a ~ e). As the edges on both sides of the main carriageway of the farmland are clear after pretreatment, so we can extract the navigation path directly. Centerline method was still used, but the scanning process was lightly different from processing road image, namely, from the middle of each row of the image to scan the left and right, noted down the values of the left and right white pixels, averaged, and finally fitted the point obtained by the least squares and the navigation path can be got, the results are shown in Figure 5 (f).

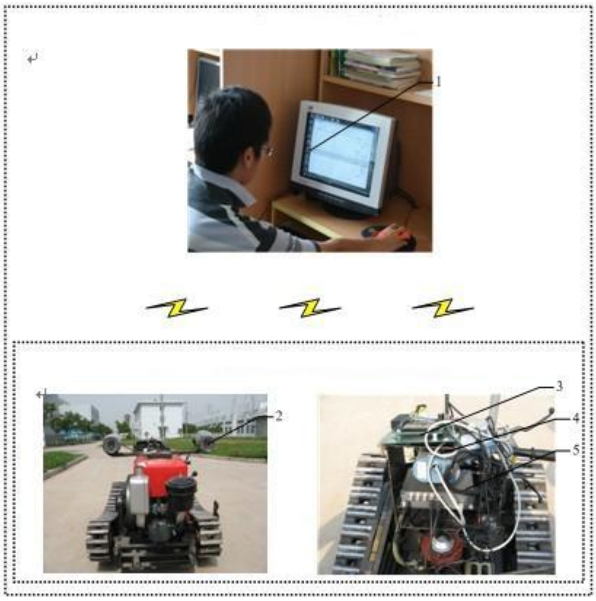
(a)farmland environment original figure (b) binarization (c) median filter

(d) fourth vertical expansion (e) eighth vertical expansion (f) navigation path extracting figure

Fig.5 The schematic diagram of field image preprocessing and extracting navigation path

IV. REMOTE MONITORING SUBSYSTEM

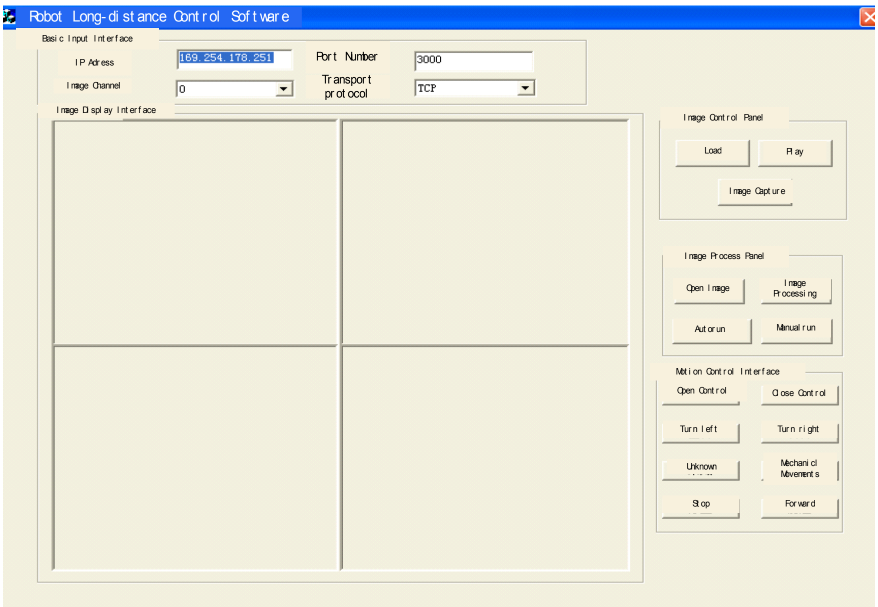
Agricultural robot can walk automatically through tracking the navigation path under the control of visual navigation subsystem in real time. However when it encounters an obstacle or a cliff, it is not able to achieve reliable navigation. So, the method combining the remote monitoring subsystem [19] and the visual navigation subsystem is proposed. Remote monitoring subsystem is composed of monitoring client software and alarm module [20], Figure 6 (a), (b) are the schematic diagrams for the experimentation and monitoring client software. The working process is: agricultural robot walks automatically through tracking the navigation path under the control of visual navigation subsystem in real time and the two-way image signals are transported to the monitoring computer in monitoring center through the real-time wireless LAN and displayed by supervision terminal software. Because supervision terminal is equipped with alarm module, the robot stops walking and sends alarm information to monitoring center if it encounters an obstacle or a cliff. The monitoring center receives information and starts the alarm, the operator then can send control commands to the robot through the monitoring software to process unexpected situations. Switching between visual navigation subsystem and remote monitoring subsystem is achieved by supervision terminal software button in order to ensure error-free operation of the system. The experiments verify that the monitoring subsystem has a good real-time control performance, stable image transmission. It effectively assists visual navigation subsystem and achieves the desired purpose.



(a) The physical diagram of remote monitoring system

(1. monitoring machine; 2 camera; 3 control circuit board;

4 front-end wireless bridge; 5 video encoder)



(b) Remote control software interface

Fig.6 The schematic diagram of remote monitoring and control subsystem

V. SYSTEM DEBUG EXPERIMENT

a. Experimental site

Agricultural robots run in the experimental field located at the back of the Mechanical and Electronic College, Northwest A&F University, Yangling, Shaanxi, China. Central Laboratory of the college is the monitoring center. 100 meters between the robot and the monitoring center; sunny, wind 1-2 level, no significant noise.

b. Experimental device

The main test equipments are shown in Table 3

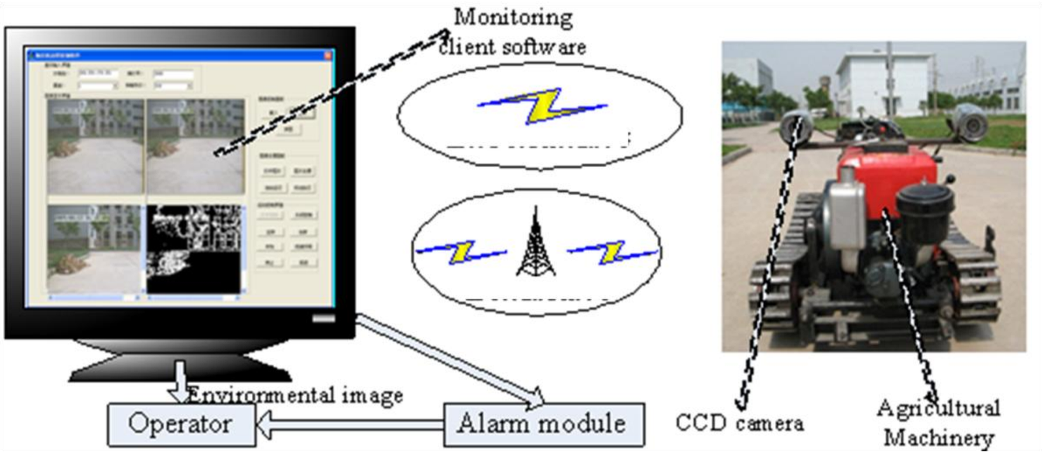
Table 3: The list of devices for experiment

Category	Device
Agricultural robot platform	Dongming, Shaanxi Science and Technology Co., Ltd.
Monitoring center	Monitoring machine、Control signal transmitting antenna
Control signal wireless transmission network	KYL-320H Wireless data transmission receiver module、KYL-320M Wireless data transmission receiver module、Control signal receiving antenna
Image signal wireless transmission network	Front-end and back-end wireless bridge、Video encoder、Omni-directional antenna

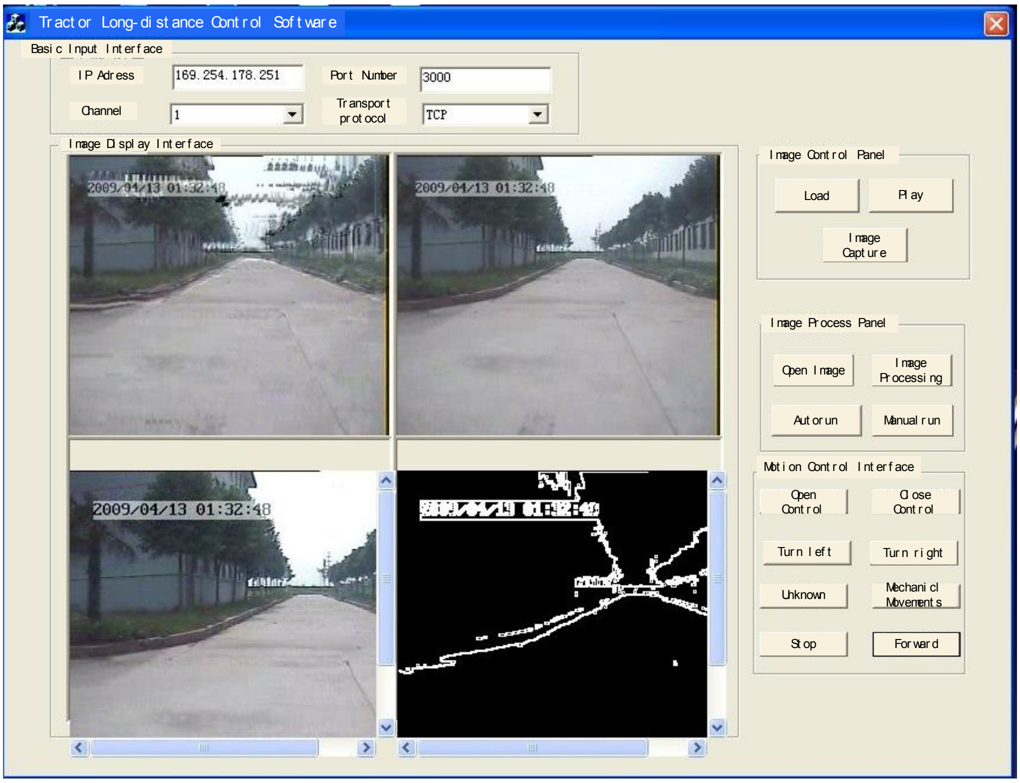
c. Experiment Results

Robots walked from the laboratory on the cement road before they reached the experimental fields, the navigation effect is good, the image of the supervision terminal is clear and stable. Figure 7 (a) shows the effect of remote monitoring test, figure 7 (b) shows the display of the remote control software interface.

Arriving at the experimental field, the robots took the crop rows as the edge and extract navigation path in the field in real time. The distance of crop rows is 1.5 m, robot width is 1 m. robots walked along the center line of the two crop rows. When encountering an obstacle, the robot automatically suspend the walking and send alarm signals to the monitoring center side through controlling signal wireless transmission network, the monitoring center receives the alarm signal and starts the alarm module, then a operator starts a wireless monitoring mode through the end of the monitoring software of the monitoring center, manually sends control commands to the robot, controls robot's movement state with wireless method, makes it shying away from the obstacle. If an obstacle is larger, then artificial scene processing is needed, the experiment shows that the delay of control signal wireless transmission is less than 10 ms, fully meet the wireless control requirements of the agricultural robot in real-time.



(a) The effect diagram of remote monitoring experiment



(b) Remote control software interface in the experiment

Fig.7 The experimental results of remote monitoring and control subsystem

VI. CONCLUSIONS

(1) Proposed a new idea which combining the visual navigation and remote monitoring to improve navigation reliability;

(2) Based on this idea, developed the appropriate hardware and software, built the corresponding subsystem;

(3) Field experiments showed that achieving agricultural robot navigation under the dual control of visual navigation subsystem and remote monitoring subsystem can not substantially reduce the labor intensity of only the operators, but also solve the problem of unreliability when agricultural robots encounter an obstacle or a cliff. It also overcomes many shortcomings which exist on traditional control methods with only one system.

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