Agricultural Machinery Movement Navigation System based on Binocular Vision Detection Technology

Chengcheng Wang[1], Yaqiu Liu[2], Peiyu Wang[3]

[1,2] School of Information and Computer Engineering, Northeast Forestry University, Harbin 150056, China
[3] School of Electromechanics Engineering, Northeast Forestry University, Harbin 150056, China

Abstract

The traditional field test method for agricultural machinery navigation system is constrained by the growth state of the crop. The problem of missing the appropriate period of crop growth will directly lead to the extension of the development cycle and the increase of the cost. In this paper, a new method of binocular vision navigation test of agricultural machinery based on virtual reality technology is put forward. The method takes agricultural machinery as the working machine, and the seedling stage cotton is the target crop. In the virtual reality environment, the three-dimensional geometric model of the field crop row scene is set up. The field path which is identified by the binocular vision method is the target path. According to the relative position relationship between the current driving path and the target path of the agricultural machinery, the model steering wheel angle is calculated and controlled before the agricultural machinery. The results show that the virtual experiment system designed in this paper can carry out the navigation experiment based on binocular vision in the field environment of the field, which can provide theoretical basis and experimental data for the test and improvement of the navigation control system.

Keywords: Binocular Vision Detection, Agricultural machinery movement, Motion tracking, Navigation

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1. Introduction

Automatic agricultural navigation technology is an effective way to increase crop yield under limited planting area. Visual sensors can acquire abundant environmental information, making the flexibility and adaptability of machine vision navigation more powerful than that of satellite navigation system [1], [2].

According to different image processing methods, machine vision navigation methods can be divided into monocular vision navigation and binocular vision navigation. Binocular vision navigation system can get the spatial information of scenery and has better adaptability to the environment with relative elevation difference between crops and weeds [3]-[5].

In order to improve the accuracy of visual navigation in complex environment, researchers have made in-depth research in the design of navigation line recognition methods and path tracking control methods. Field experiment is a necessary step in the development of agricultural navigation system. At present, the development of agricultural navigation system needs repeated design, manufacture and testing based on the field test results [6], [7].

The field test of agricultural navigation system has strong dependence on seasons, and is influenced by factors such as region, climate and crop growth status [8], [9].

Therefore, the traditional development of agricultural machinery navigation system is also constrained by the season. The period of missing the appropriate growth period of the crop will lead to the extension of the development cycle and the increase of cost. Virtual reality technology can be identified in various aspects before product production, which will facilitate the improvement of design, development efficiency and cost reduction [10], [11].

The application of virtual reality technology in agricultural machinery field is mainly focused on the design and manufacture of agricultural machinery products, and there are some examples of successful application in the virtual experiment of agricultural machinery products, but there is no clear report on the experimental research of agricultural machinery navigation system [12]-[14].

Commercial visual simulation tools provide convenience for configuring virtual test scenarios. How to simulate the physical properties and working process of agricultural navigation system in three-dimensional virtual test scenario is the focus of virtual experimental research.

To sum up, the use of virtual reality technology in the 3D virtual environment to carry out experimental research on agricultural machinery navigation system is a new way to improve the efficiency of development and save the cost of development [15]-[18].

In this paper, a new method of agricultural machinery navigation based on virtual reality technology is proposed in this paper, which takes agricultural machinery as the working machine, the seedling stage cotton as the target crop and the binocular vision navigation as the navigation mode.

2. Virtual Experiment Scene Modelling

A virtual test scenario model was established to simulate the actual field test environment [19], [20]. With 3ds Max and Creator as modelling tools, the model data format is Open Flight (FLT) format supported by VP software. The virtual experiment scene is composed of tractors, crop rows and pavement. The modelling process is as follows:

1) Establishment of agricultural machinery model, only considering the appearance characteristics of agricultural machinery and neglecting its internal structure.
2) Establish a cotton crop row model with weed interference. According to the morphological characteristics of cotton at seedling stage, leaf models, petiole models and main stem models were established to form a cotton monomer model. The characteristics of weed disturbance were simulated by using wheat straw and Oxalis clover in typical cotton field, and the corresponding geometric models were established. According to the morphological characteristics of mechanized strip or on demand cotton crop line, cotton is placed in the virtual experiment scene in accordance with certain spacing and spacing, and weed model is arranged randomly in the designated plane area to simulate weeds interference, thus the crop row model is formed.
3) Build the road model. The road surface model consists of appearance features and road roughness information. Among them, the pavement appearance is expressed by texture map of the road surface image. The road roughness information is created according to the mean value of the road surface elevation variation, using the fractal tool of 3DS Max.

Table 1. Statistics of scenes for test

Name	Value	Name	Value
Average height of cotton /m	0.3	Base line distance /m	0.12
Average height of weeds /m	0.1	Focal length of camera /m	0.0038
Average space of crop rows adjacent to the wheels /m	1.2	Angles of field view	66×42
Average space of the outmost crop rows /m	0.76	Pitch angles of eye point	50
Crop rows	5	Height of eye point/m	1.13

According to the test parameters in Table 1, a virtual test scenario model is established. According to the distance of agricultural machinery, cotton cultivation, matching equipment size information and limited camera field, 5 curves of continuous cotton crop rows were arranged by size row spacing pattern. The way to track the farm machinery is to track the line, and the wheel crosses 1 crops.

The row spacing of the crops in the adjacent sides of the wheel is 1.2 m, and the distance between the most lateral crops is 0.76 m. The average height of cotton and the average height of weeds were set according to the field measured data. In VP software: configuring projection mode, setting baseline distance, focal distance and field angle parameters based on 1 parallel binocular camera (BB2-08S2-38) [21], [22], to simulate the imaging effect of the camera, configure the position and position of the view point, and simulate the relative position and posture of the camera and the body and the ground in the image acquisition system [23].

Figure 1. Scenes for virtual test

The rendering effect of the virtual test scenario model in VP environment is shown in Figure 1. In this figure, the initial alignment of agricultural machinery is located in the central 1 crop rows. The path tracking process is based on the crop behaviour target path. Weed characteristics in curvilinear rows can simulate the weed noise in actual field crops. After configuring the position and position of the point of view in Table 1, a RGB image of 640 pixel*480 pixel is set. The left and right eye images can approximate the cotton crop lines with high density of weeds and are used to identify the navigation lines.

3. Physical Engine Modelling

3.1 Mathematical modelling of whole vehicle

A vehicle model was established to simulate the dynamic state of agricultural machinery. The agricultural machinery in this paper is the structure of front wheel steering, rear wheel drive and brake, and there is no suspension system. In the agricultural machinery navigation test research, the speed is usually low. The following simplification is made in modelling the whole vehicle: simplifying the body of wheel to the rigid connection. The steering angle of the front wheel conforms to the Ackerman steering geometry theory.

The agricultural machinery is simplified to 11 degree of freedom vehicle dynamics model, as shown in Figure 2.

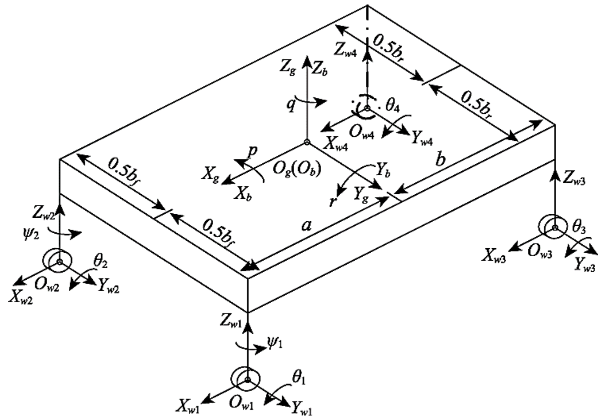

Figure 2. Vehicle model of tractor

Specifically, the 3 axial movement degrees of freedom of the body are included.(X_b, Y_b, Z_b), m. The rotation of freedom of the 3 body of the body (p, q, r), rad. 4 wheel rolling degrees of freedom θ_i, rad, i=1, 2, 3, 4. The left front, right front, left rear and right rear wheels are shown in turn. 1 front wheel steering degrees of freedom, and the steering angles of the left and right front wheels are respectively ψ_1, ψ_2, rad.

According to Euler kinematics equation, the inertia moment vector Mt of the external force of agricultural machinery to the centre of mass is calculated.

$$M_t = I_t \dot{\omega}_t + \tilde{\omega}_t I_t \omega_t \tag{1}$$

$\omega_t = [\omega_{tx}, \omega_{ty}, \omega_{tz}]^T$ is the angular velocity matrix of agricultural machinery. $\dot{\omega}_t$ as angular acceleration matrix rad/s^2, $\tilde{\omega}_t$ is the angular velocity opposed to the array of agricultural machinery. rad/s is the inertia tensor matrix of the whole farm vehicle relative to $O_b - X_bY_bZ_b$, $kg \bullet m^2$. $\tilde{\omega}_t$ and I_t are respectively expressed as

$$\tilde{\omega}_t = \begin{bmatrix} 0 & -\omega_{tz} & \omega_{ty} \\ \omega_{tz} & 0 & -\omega_{tx} \\ \omega_{ty} & \omega_{tx} & 0 \end{bmatrix}, I_t = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{bmatrix} \tag{2}$$

Simultaneous (1)~(2) can obtain M_t inertia moment component (M_{tx}, M_{ty}, M_{tz}) on X_b , Y_b , Z_b axis.

$$\begin{cases} M_{tx} = I_{xx}\dot{\omega}_{tx} + I_1\omega_{ty}\omega_{tz} - (\omega_{tx}\omega_{ty} + \dot{\omega}_{tz})I_{xz} \\ M_{ty} = I_{yy}\dot{\omega}_{ty} + I_2\omega_{tx}\omega_{tz} + (\omega_{tx}{}^2 - \omega_{tz}{}^2)I_{xz} \\ M_{tz} = I_{zz}\dot{\omega}_{tz} + I_3\omega_{tx}\omega_{ty} + (\omega_{ty}\omega_{tz} - \dot{\omega}_{tx})I_{xz} \\ I_1 = I_{zz} - I_{yy}, I_2 = I_{xx} - I_{zz}, I_3 = I_{yy} - I_{xx} \end{cases} \tag{3}$$

In the form, I_1, I_2, I_3 are respectively intermediate variables. The mechanical analysis of farm machinery is carried out and the mechanical equation of agricultural machinery is established. When agricultural machinery is automatically navigating, the speed is usually low and the air resistance is negligible. The mechanical equation of the whole vehicle is set up (4).

$$\begin{cases} ma_{tx} = \sum_{i=1}^{4}\left(F_{wxi}\cos\psi_i - F_{wyi}\sin\psi_i\right) \\ ma_{ty} = \sum_{i=1}^{4}\left(F_{wxi}\sin\psi_i + F_{wyi}\cos\psi_i\right) \\ ma_{tz} = \sum_{i=1}^{4} F_{wzi} - mg \end{cases} \tag{4}$$

F_{wzi}（i=1,2,3,4）is the vertical force acting on the tire, m is the quality of the whole farm machinery.

3.2 Mathematical modelling of tires

The tire model of agricultural machinery was established to simulate the ground mechanical properties of the tire. Tire is difficult to describe its nonlinear characteristics through a unified model. Typical tire models include magic formula, UniTire model and Dugoff model. In order to improve the real-time performance of the simulation and reduce the difficulty of obtaining tire parameters, the Dugoff first models are used to simulate the ground mechanical characteristics of the tire approximately. The tire coordinate system and the force conditions are shown in Figure 3.

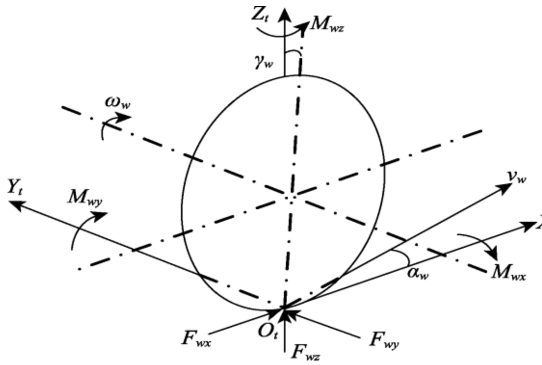

Figure 3. Dugoff model of tire

In Figure 3, the origin of the tire coordinate system O_t is the intersection point between the intersection line between the tire plane and the ground plane and the axis of the tire rotation on the ground plane. The X_t axis is the intersection of the tire plane and the ground plane, and the right direction points to the direction of the tire. The Y_t axis is directed to the left side of the tire plane through O_t. The Z_t axis passes through O_t and perpendicular to the ground plane, pointing upward in the positive direction. According to the Dugoff first tire model, the tire camber and the return torque are ignored, and the tire longitudinal force F_{wx} and the lateral F_{wy} are not locked when the wheels are not locked.

$$\begin{cases} F_{wx} = \dfrac{C_x s_x}{1-|s_x|} f(\lambda) \\ F_{wy} = -\dfrac{C_y \tan\alpha_w}{1-|s_x|} f(\lambda) \end{cases} \tag{5}$$

Type C_x and C_y are tire longitudinal stiffness and lateral stiffness, respectively. N/rad , s_x is the longitudinal sliding rate of the tire, α_w is the side angle of the tire, rad .

$f(\lambda)$ is a function of the dynamic parameter λ of the tire, It is used to describe the nonlinear characteristics of tires, which can be expressed as

$$f(\lambda)=\begin{cases}\lambda(2-\lambda), \lambda \prec 1\\ 1, \lambda \geq 1\end{cases} \tag{6}$$

The tire dynamic parameter λ represents the boundary condition of $f(\lambda)$, and determines the calculation form of tire longitudinal force and lateral force. The specific calculation method of λ is

$$\lambda=\frac{\mu F_{wz}(1-|s_x|)}{2\sqrt{(C_x s_x)^2+(C_y \tan\alpha_w)^2}} \tag{7}$$

The vertical type of the tire is simplified as a rigid damping system. The vertical ground reaction force F_{wzi} is approximately calculated according to the deformation of the tire, as shown in equation (8).

$$\begin{cases}
\mathrm{F}_{wz1}=k_{wz1}\triangle \mathrm{z}_{w1}+C_{wz1}\dot{z}_{w1}+\dfrac{mgb}{2L}\\
\mathrm{F}_{wz2}=k_{wz2}\triangle \mathrm{z}_{w2}+C_{wz2}\dot{z}_{w2}+\dfrac{mgb}{2L}\\
\mathrm{F}_{wz3}=k_{wz3}\triangle \mathrm{z}_{w3}+C_{wz3}\dot{z}_{w3}+\dfrac{mga}{2L}\\
\mathrm{F}_{wz4}=k_{wz4}\triangle \mathrm{z}_{w4}+C_{wz4}\dot{z}_{w4}+\dfrac{mga}{2L}
\end{cases} \tag{8}$$

In the form, $\triangle \mathrm{z}_{wi}$ is the vertical deformation of the tire,m, k_{wzi} is the vertical stiffness of the tire, N/m, C_{wzi} F is the vertical damping of the tire.L is the wheelbase of the agricultural machinery, $L=a+b, m$.

3.3 *Mathematical modelling of pavement calculation*

A pavement settlement model is established to calculate the tire road roughness excitations based on road information in the VP virtual test scenario. The pavement calculation model is based on the ground crawling (VP GroundClamp) module and the three foot (tripod) collision detection module in the VP software. By detecting the fluctuation of the field pavement in the experimental scene, the road roughness of each tire is calculated. The VP Ground Clamp module is used to realize the tire follow the road movement, and the tire position is modified by the Tripod module, so that the tire stays above the ground. The road roughness calculation model is shown in Figure 4.

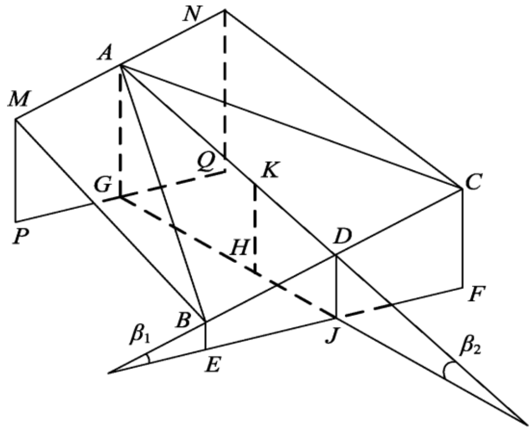

Figure 4. Solution model of road roughness

In Figure 4, three lines of *AB*, *AC* and *BC* are used for collision detection, and the triangular plane Δ*ABC* is constructed by 3 collision points. The road roughness is approximated according to the position and orientation of the detected Δ*ABC* plane centre normal vector （KH, θ_1, θ_2）. Calculation of road roughness corresponding to agricultural machinery tire based on triangular geometry relationship $(z_{w1}, z_{w2}, z_{w3}, z_{w4})$, The concrete calculation method is as follows.

$$\begin{cases}
z_{w1}=MP=AG-0.5b_f\sin 1\\
z_{w2}=NQ=AG+0.5b_f\sin 1\\
z_{w3}=BE=DJ-0.5b_r\sin 1\\
z_{w4}=CF=DJ+0.5b_r\sin\theta_1\\
AG=KH+AK\cdot\sin\theta_2\\
DJ=KH-KD\cdot\sin\theta_2\\
AK=2L/3, KD=L/3
\end{cases} \tag{9}$$

3.4 *Motion path tracking control method*

Binocular vision is used to identify the centre line of crop rows and extract the navigation target path. Using the method in the literature to identify the crop line centre line, the specific process is as follows:

1) using the improved super green feature method to get the grey image;
2) using the minimum kernel similarity operator to extract the feature of the plant corner;
3) the result of the grey value Rank transform is the parallax of the matched base element detection angle, and the 3D coordinates of the corner points are calculated;
4) The crop row characteristic points are extracted according to the height and width threshold;
5) by using the frequency histogram method, the crop row characteristic points are classified according to the line of line in the width direction, and
6) the crop line centre line is fitted by the principle component analysis method based on random sampling.

As shown in Figure 1a, the agricultural machinery tracks the path of the middle crop line (i.e. the crop row in the middle area of the image) and sets the line of the crop line as the target navigation path. The position deviation calculation model is constructed, and the position deviation d_{tp} and heading deviation φ_p between the agricultural machinery and the target path are calculated according to the current driving path and the target path parameters of the agricultural machinery. The current running path of agricultural machinery coincides with the X_p axis of O_p-X_pY_p in the path coordinate system. The original state O_p is located at the centre of mass of agricultural machinery.

4. Test and Result Analysis

According to the virtual navigation test method proposed in this paper, the software system is developed by using C++ language in the environment of Visual Studio 2015. The software system is a multi-thread structure [24]. The visual rendering thread is based on the two development of the VP 3D virtual simulation module for real-time rendering of the experimental scene and the movement posture of the agricultural machinery [25]. The image processing thread identifies the navigation path by collecting the cotton crop line information in the test scene, and the physical engine thread integrates the physical engine module and the path tracking controller module. It is used to simulate the dynamic state of agricultural machinery and control the tracking path of agricultural machinery. Taking a certain type of farm machinery parameter in Table 2 as the test scenario of the crop row scene in parameter 1 of the vehicle, simulation experiments were carried out on the computer. The computer's processor model is Inter(R) Core(TM) i7-4440 @ 3.10 GHz, the memory is 8 GB and the operating system is 64 bit Windows 10. A virtual experiment of crop tracking was conducted to test the performance of the virtual navigation test system.

Table 2. Parameters of tractor

Name	Value	Name	Value
m/kg	6850	$I_{zz}/kg\cdot m^2$	3424
T_{yf}	14.9-26	$I_{xx}/kg\cdot m^2$	1814
T_{yr}	18.4-38	$I_{xz}/kg\cdot m^2$	202
$r_{ws1}, r_{wx2}/m$	0.600	$C_{x1}, C_{x2}/(N\cdot rad^{-1})$	350000
$r_{ws3}, r_{ws4}/m$	0.870	$C_{y1}, C_{y2}/(N\cdot rad^{-1})$	340000
a/m	1.570	$k_{wz1}, k_{wz2}/(N\cdot m^{-1})$	242000
b/m	1.118	$C_{wz1}, C_{wz2}/(N\cdot s\cdot m^{-1})$	4000
h_g/m	1.5	$C_{x3}, C_{x4}/(N\cdot rad^{-1})$	350000
b_f/m	1.350	$C_{y3}, C_{y4}/(N\cdot rad^{-1})$	340000
b_r/m	1.300	$k_{wz3}, k_{wz4}/(N\cdot m^{-1})$	262000
$I_{yy}/kg\cdot m^2$	3548	$C_{wz3}, C_{wz4}/(N\cdot m^{-1})$	5200

The virtual experiment scene is shown in Figure 1. The projection display effect of a crop row scene in virtual reality system in virtual experiment is shown in Figure 5.

Figure 5. Scene of virtual test for tractor guidance

In Figure 5, the cotton field scene is composed of 5 similar parallel crops. The average length of crop rows is about 60 m, and the random distribution of weeds in the range of -45 m to -60 m. The initial position and course of the agricultural machinery are aligned with the crop rows located in the middle of the image (third lines of the image). In the visual navigation test, the farm machinery is tracked as the target crop line in the centre of the image in the middle of the image.

According to the contour range (1.67 m) of the locomotion track on both sides of the farm machinery and the row spacing (1.2 m) on the adjacent side of the wheel, the maximum value of the allowable lateral displacement of the mass centre of the agricultural machinery is 0.365 m. After setting up agricultural machinery to start 1 s, start tracking crop line, stop tracking at forty-sixth s after starting, brake after starting forty-eighth s.The start speed of agricultural machinery is 0.3 m/s, the longitudinal speed of tracking crop rows is 1 m/s, and the speed of the simulation is 0.2 m/s at the end of the simulation. The virtual test results of agricultural machinery tracking crop line are tracking trajectory, left front wheel steering angle, position deviation and heading deviation. The trace contour has a certain distance from the adjacent crop rows, indicating that the wheels are not rolled to cotton crops. As shown, the deviation of the navigation position is uniform and no larger mutation is observed, which indicates that the tracking effect of agricultural machinery on curvilinear crop rows is better. The test data of position deviation in the process of crop tracking of agricultural machinery tracking curve: the maximum amplitude of position deviation is 0.319 m, less than the maximum allowable deviation value (0.365 m), which indicates that the navigation path of visual recognition is always located in the line of target crops and does not occur cross line phenomenon. The average value of position deviation is 0.069 m, standard the difference is 0.132m.

The maximum amplitude of heading deviation is 9.980°, the average value is 2.267°, standard deviation is 4.227°.

The influence of longitudinal speed of agricultural machinery (hereinafter referred to as vehicle speed) on the tracking effect of crops was investigated. Crop tracking tests were carried out at 0.5, 1.5, 2, 2.5 and 3 m/s speeds in the same virtual environment as above. The test results of steering angle, position deviation and heading deviation of the left front wheel of farm machinery tracked at different speeds are shown in Table 3.

Table 3. Statistics of tracking for crop rows at different speeds

$v_t/(m\cdot s^{-1})$	$\psi_1/(^\circ)$			ψ_{tp}/m			$\psi_p(^\circ)$		
	MA	MV	STD	MA	MV	STD	MA	MV	STD
0.5	10.863	-0.331	2.221	0.347	-0.033	0.141	10.796	1.114	4.462
1	13.619	-0.206	2.998	0.319	-0.069	0.132	9.980	2.267	4.227
1.5	14.838	-0.132	3.892	0.298	-0.032	0.132	11.570	1.083	4.046
2	18.991	0.166	5.274	0.309	-0.072	0.122	8.475	2.622	3.488
2.5	25.022	1.552	11.888	0.655	-0.073	0.208	14.804	2.610	5.519
3	26.914	1.615	10.346	0.729	-0.135	0.199	17.773	3.298	6.027

In Table 3, the path tracking controller of this paper, tracking effect of agricultural machinery to crop rows is better within the speed range of 2 m/s, the deviation of flight position is small and the amplitude of steering angle of front wheel is small: the maximum amplitude of position deviation is not more than 0.347 m, the absolute value of the average value is not more than 0.072 m, and the standard deviation is not more than 0.141 m. The maximum amplitude of heading deviation is not more than 11.570°, The absolute value of the mean value is not more than 2.622°, The standard deviation is not more than 4.462°, The maximum amplitude of the steering angle of the front wheel is not more than 18.991°, The absolute value of the mean is not more than 0.331°, The quasi difference is not greater than 5.274°. When the speed of the vehicle is more than 2 m/s, the amplitude of the steering angle of the front wheel increases obviously and turns frequently, causing the side slip of the front wheel tire, the agricultural machinery swings around the driving, the vibration amplitude of the fuselage is larger, and the tracking effect of the crop row is poor.

5. Conclusion

The designed virtual navigation test system can effectively simulate the field crop row environment in the virtual reality environment and carry out the agricultural machinery navigation test based on binocular vision. The experiment process is convenient and low cost. It avoids the dependence of the traditional test mode on the crop growth cycle and the experiment process. It is easy to cause damage to crops. The test results conform to the laws of physics, which can provide theoretical basis and experimental data for the test and improvement of navigation control system. The track tracking control system designed in this paper has high tracking precision when the speed of agricultural machinery is less than 2 m/s, but the steering wheel is more frequent. In the future research, the back positive effect of the tire is considered, and the parameters of the PID controller are adjusted according to the speed of the vehicle.

6. Bibliographic References

[1] Lü Antao, Song Zhenghe, Mao Enrong. Optimized control method for tractor automatic steering[J]. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, 2019, 22(8), pp. 116-119.

[2] Meng Qingkuan, Qiu Ruicheng, Zhang Man, et al. Navigation system of agricultural vehicle based on fuzzy logic con-troller with improved particle swarm optimization algorithm[J]. *Transactions of the Chinese Society for Agricultural Machinery*, 2017, 46(3), pp. 29-36.

[3] Li Taochang, Hu Jingtao, Gao Lei. Robust adaptive path tracking control of agricultural machines based on cascaded control strategy[J]. *Robot*, 2019, 36(2), pp. 241-249.

[4] Karkee M, Steward B L, Kelkar A G, et al. Modelling and real-time simulation architectures for virtual prototyping of off-road vehicles[J]. *Virtual Reality*, 2017, 15(1), pp. 83-96.

[5] Inoue S, Ojika T, Harayama M, et al. Cooperated operation of plural hand-robots for automatic harvest system[J]. *Mathematics and Computers in Simulation*, 2019, 41(3), pp. 357-365.

[6] Melemez K, Gironimo G D, Esposito G, et al. Concept design in virtual reality of a forestry trailer using a QFD-TRIZ based approach[J]. *Turkish Journal of Agriculture and Forestry*, 2016, 37(6), pp. 789-801.

[7] Hu Jingtao, Gao Lei, Bai Xiaoping, et al. Review of research on automatic guidance of agricultural vehicles[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2019, 31(10), pp. 1-10.

[8] Zhai Zhiqiang, Du Yuefeng, Zhu Zhongxiang, et al. Three-dimensional reconstruction method of farmland scene basedon Rank transformation[J]. *Transactions of the Chinese Society of Agricultural Engineering*. 2015, 31(20), pp. 157-164.

[9] Kise M, Zhang Q, Rovira-Más F. A stereovision-based croprow detection method for tractor-automated guidance[J].*Biosystems Engineering*, 2019, 90(4), pp. 357-367.

[10] Zhai Zhiqiang, Zhu Zhongxiang, Du Yuefeng, et al. Methodfor detecting crop rows based on binocular vision with Census transformation[J]. *Transactions of the Chinese Society of Agricultural Engineering*, 2016,32(11), pp. 205-213.

[11] Han S, Zhang Q, Ni B, et al. A guidance directrix approach to vision-based vehicle guidance systems[J]. *Computers and Electronics in Agriculture*, 2019, 43(3), pp. 179-195.

[12] Zhu Zhongxiang, He Yan, Zhai Zhiqiang, et al. Research on cotton row detection algorithm based on binocular vision[C], *Proceedings of 4th International Conference on Applied Mechanics, Materials and Manufacturing*, Shenzhen, China, 2019, pp.1222-1227.

[13] Takagaki A, Masuda R, Iida M, et al. Image processing for ridge/furrow discrimination for autonomous agricultural vehicles navigation[J]. *IFAC Proceedings Volumes*, 2019,46(18), pp. 47-51.

[14] Guerrero J M, Guijarro M, Montalvo M, et al. Automatic expert system based on images for accuracy crop row detection in maize fields[J]. *Expert Systems with Applications*, 2015, 40(2), pp. 656-664.

[15] Åstrand B, Baerveldt A J. A vision based row-following system for agricultural field machinery[J]. Mechatronics,2018, 15(2), pp. 251-269.

[16] Min qi, Huang Yingping. Moving object detection based on stereo vision and optical flow fusion[J]. Optical technology, 2018,12 (1), pp. 28-33.

[17] Daubechies I. The wavelet transforms time-frequency localization and signal analysis [J]. *IEEE-IT*,2016,2(4), pp. 961-1005.

[18] Huo Yanyan, Huang Yingping. Obstacle Detection Method Based on Stereo Vision and Optical Flow[J]. *Information Technology*, 2020, 6(1), pp. 125-127.

[19] Annika Kuhl. Tractor Motion Control Based on Binocular Detection Technology[J]. *Automatic Control Technology*, 2017, 11(1), pp. 125-127.

[20] Yu Yong, Zhang Hui, Lin Maosong. Research and design of three-dimensional reconstruction system based on binocular stereo vision[J]. *Computer Technology and Development*, 2019, 13(6), pp. 6-10.

[21] Meng Qingkuan, Qiu Ruicheng, Zhang Man, et al. Navigation system of agricultural vehicle based on fuzzy logic con-troller with improved particle swarm optimization algorithm[J]. *Transactions of the Chinese Society for Agricultural Machinery*, 2017, 46(3), pp. 29-36.

[22] Hongkun Tian, Tianhai Wang,Yadong Liu,Xi Qiao,Yanzhou Li. Computer vision technology in agricultural automation —A review[J]. *Information Processing in Agriculture*, 2019, 7(1), pp. 85-89.

[23] Weibin Yan. Study on the Application of Computer Vision Technology in Defect Detection[C]. *Proceedings of 2019 International Conference on Computer Information Analytics and Intelligent Systems (CIAIS 2019)*. Institute of Management Science and Industrial Engineering: (Computer Science and Electronic Technology International Society), 2019, pp. 229-233.

[24] Jiang Bo, He Jinrong, Yang Shuqin, Fu Hongfei,Li Tong,Song Huaibo, He Dongjian. Fusion of machine vision technology and AlexNet-CNNs deep learning network for the detection of postharvest apple pesticide residues.,2019, 1(C), pp. 18-23.

[25] Xiaomin Liu. Research on Key Technology of Diamond Particle Detection Based on Machine Vision[C]. Shanghai University of engineering and technology. *Proceedings of 2018 2nd International Conference on Electronic Information Technology and Computer Engineering (EITCE 2018)*. Shanghai University of engineering and technology: International Academic Exchange Research Institute of Guangdong Human Resources Research Association, 2018, pp. 593-596.

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Authors' Biographies

Chengcheng Wang was born in Huludao (China), on February, 1993.
She received the Bachelor Degree in electronic information engineering from the Civil Aviation University of China in Tianjin (China), in 2015.
She received the Master Degree in computer technology from the Northeast Forestry University in Harbin (China), in 2017.

She is currently a PhD candidate in Forestry information engineering in the Northeast Forestry University, China.
Her research interests concern: dynamic target detection and image segmentation
e-mail: 1062278235@qq.com

Yaqiu Liu received his BS in Electrical Engineering from Harbin Institute of Electrical Technology in 1994.
He received the Master degree in Control Theory and Engineering from Northeast Forestry University in 1999 and PhD in Navigation, Guidance, and Control from Harbin Institute of Technology in 2004.
He is currently a Professor of Northeast Forestry University. His research interests include process control, intelligent control and soft computing and model reconstruction.
e-mail: yaqiuliu@qq.com

Peiyu Wang was born in Binzhou (China), on November, 1992.
He received the Bachelor degree in automation from the Civil Aviation University of China (China), in 2015.He received the Master degree in control engineering from the Northeast Forestry University (China), in 2017.

He is a Ph.D. candidate in Forestry Engineering Automation in Northeast Forestry University, China.
His research interests concern: Pattern recognition, image processing.
e-mail: 117365874@qq.com