Proceedings of The 2021 IEEE International
Conference on Real-time Computing and Robotics
July 15-19, 2021, Xining, China

Research on AGV Navigation System Based on Binocular Vision *

Changsheng Ai , Dunyang Geng , Zhengguang Qi, Lei Zheng, Zhiquan Feng

***Abstract*—Aiming at the problems that the traditional single sensor of AGV cannot meet the indoor and outdoor operating conditions and the cost of multiple sensors is too high, this paper proposes an AGV navigation method using binocular camera. The binocular camera is used to identify the lane line and obtain the pose deviation of the vehicle body relative to the lane line, and then track the path.The depth information of obstacles is obtained by using binocular parallax principle, and then the vehicle body is protected safely.The pose deviation of the vehicle body relative to the lane line obtained by the proposed binocular camera was verified by experiments. The experimental results show that the pose information obtained by the binocular camera is reliable and stable, and meets the requirements of AGV navigation.The use of binocular vision AGV navigation system, can be suitable for navigation.**

keyword：Binocular camera，Pose to extract，Path tracking

I. Introduction

Automatic Guidance Vehicle (AGV) is a transportation platform equipped with a variety of Guidance devices, capable of driving along the set route, with safety protection and load shifting devices.In today's automatic production process, has been more and more widely used.At present, the guidance methods of AGV mainly include laser guidance, electromagnetic guidance, inertial guidance and visual guidance.Compared with the electromagnetic guidance mode of AGV, the visually-guided AGV has the characteristics of convenient layout and simple maintenance [1].

Compared with the laser guided AGV, the visually guided AGV has the characteristics of low cost, not easy to damage and wide application fields [2].

America's Carnegie Mellon University, Ford and NASA jointly developed the AMTS project [3].The project brings together computer, image processing and automatic control software technology, mainly including visual navigation guide vehicle positioning system, cargo grabbing system and path planning system.

The visual navigation automatic guidance vehicle developed by Jiangtao Wang [4] adopts the monocular vision system for navigation, and is equipped with a computer and image processor. The monocular camera can rotate freely and comprehensively detect the surrounding information. At the same time, the rotary encoder and potentiometer are used to obtain the driving distance and turning Angle, so as to complete the positioning.

Jiajie Yao [5] proposed an adaptive road detection algorithm based on vision cluster analysis through the study of road recognition methods. Through the automatic selection of road samples, the sample addition of the autonomous navigation vehicle without human participation was realized, overcoming the defects of the learning algorithm.Yao Jiajie proposed a path tracking algorithm suitable for simple road conditions on the basis of road recognition algorithm. By extracting the center line of the road as the reference line of automatic navigation vehicle, the smooth operation of the navigation vehicle in simple environment was realized.

Jinchao Li [6] proposed a classification method based on the local guiding line features obtained by visual detection and the average slope difference and inflection point resolution index, aiming at the fact that the traditional detection algorithm, which approximates all types of tracks in the image into straight line tracks by Hough transform, could not meet the measurement accuracy requirements of curve tracks.The least-mean-square error and Levenberg-Marquardt method were used to fit the trajectory models of straight lines and arcs respectively. Finally, guidance parameters were given according to different models, which improved the guidance accuracy of the visual-guided AGV.

Wan Hao [7] regards the approximate circular arc as a straight line, which greatly reduces the calculation amount and improves the real-time performance and accuracy.The average gray scale method is used to extract the left and right edge points of the lane line, and then the least square method is used to carry out linear fitting of the left and right edge points of each line to obtain the equation of the path center. After coordinate transformation, the equation of the lane line can be transformed into the linear equation of the camera coordinate system, and the lateral deviation and directional deviation can be obtained.

Ruizhu Nie [8], first of all, according to the path marker center of edge information to obtain path set, and then based on curvature Angle estimation method to categorize the path model, mainly divided into the path of beeline model, the circular arc turning model and line turn path model, and according to the characteristics of path model is derived to extract the location of the AGV navigation needed to offset and the calculation method of the deviation of the Angle.

Weiliang Shen [9] proposed a self-repairing method of dirt based on morphology, which effectively solved the interference caused by image dirt on path feature extraction.

* Reseach supported by supported by the Independent Innovation Team Project of Jinan City (No. 2019GXRC013)

Changsheng Ai is with the School Of Mechanical Engineering, University of Jinan,250022, Shandong Province, China. (Corresponding author phone: 0531-82765716, e-mail: me_aics@ujn.edu.cn).

Dunyang Geng is with the School of Mechanical Engineering, University of Jinan, Shandong Province, China.

Zhengguang Qi is with the School of Mechanical Engineering, University of Jinan, Shandong Province, China.

Lei Zheng is with the School of Mechanical Engineering, University of Jinan, Shandong Province, China.

Zhiquan Feng is with the School Of Information Science And Technology, University of Jinan,250022, Shandong Province, China.

2021 IEEE International Conference on Real-time Computing and Robotics (RCAR) | 978-1-6654-3678-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/RCAR52367.2021.9517359

Aiming at the situation that the guiding path is broken or shaded, an image shading processing method based on the least square fitting is proposed. The linear guiding path and arc turning path are fitted by the least square fitting, and the data on the fitting line or arc are used to realize the reliable guidance of the AGV at the path fracture.

In recent years, a large number of researchers have devoted themselves to the application of machine vision in AGV and made a lot of achievements. Some scholars proposed to use monocular camera for navigation, but monocular camera requires continuous rotation to obtain driving distance and turning Angle. Compared with binocular camera, the calculation amount is large and the calculation time is long.Some scholars use machine learning algorithm to select road samples, but the stability is not enough in the face of complex environment.Some scholars fit the lane lines into different models, but the complexity of the program is increased and the stability is not enough.Most scholars only use visual sensors for navigation, and additional sensors are needed for vehicle safety protection. However, binocular cameras can not only directly obtain object depth information for obstacle avoidance, but also obtain image data for navigation and positioning.Based on this, this paper proposes an AGV navigation system based on binocular vision.

II. HARDWARE SCHEME DESIGN

A. Principle of parallax in binocular camera

Binocular camera can obtain image data through two cameras and calculate parallax to obtain object depth data[10]. Figure 3 shows the principle of depth data acquisition by binocular camera

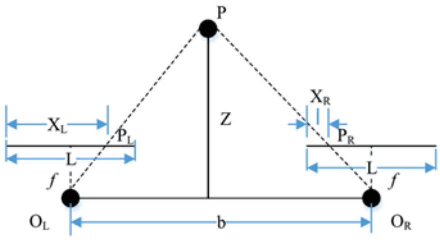


Figure 1 principle of parallax ranging for binocular camera

As shown in Figure 1, b is the camera baseline, P is any point in the space, PL is the imaging point of the left camera, and PR is the imaging point of the right camera.Line segments XL and XR are the distances from the imaging points of the left and right cameras to the left imaging plane respectively, then the parallax of P in the left and right cameras can be defined as follows:

$$d = |X_L - X_R| \tag{1}$$

The distance between two imaging points PL and PR is:

$$P_L P_R = b - \left(X_L - \frac{L}{2}\right) - \left(\frac{L}{2} - X_R\right) = b - (X_L - X_R) \tag{2}$$

According to the similar triangle theory, it can be concluded:

$$\frac{b-(X_L-X_R)}{Z-f} = \frac{b}{Z} \tag{3}$$

Then, the distance Z from point P to the central plane of the projection can be obtained:

$$Z = \frac{b*f}{X_L-X_R} \tag{4}$$

When point P moves in space, the imaging points of the left and right cameras will also change and so will the parallax. If the baseline and focal length of the camera are known, the parallax is inversely proportional to the depth distance Z, and the depth information of the object can be obtained by calculation of Equation (4).

B. Obstacle distance obtained by binocular camera

Of binocular camera for obstacle distance steps as shown in figure 2: after the front of the camera collected image, image depth information acquisition, after dealing with the obstacles algorithm, get in front of the obstacle distance data, using this data, vehicle obstacle detection, can be used as a vehicle safety barrier depth data source.

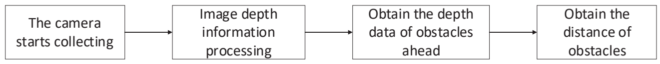


Fig. 2 Steps of obtaining obstacle distance with binocular camera

C. Binocular camera forward obstacle avoidance detection

In the safety protection part of the vehicle body, as the binocular camera can directly obtain the depth data of objects in the common view area, as shown in Figure 3, the binocular camera directly uses the forward obstacle avoidance detection function, and can visually select the obstacles in front with a rectangular frame, and display the distance, speed, number and other information from the binocular camera.

With this function, the binocular camera can be used as the safety protection sensor in the medium and long distance, and other sensors such as millimeter wave radar or safety laser thunder method can also be used as the safety protection sensor of the car body.

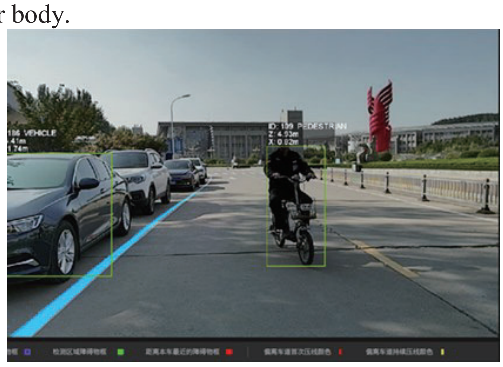


Figure 3 Forward Obstacle Avoidance Detection Function of Binocular Camera

After obtaining the image data of the binocular camera, not only the depth information is processed, but also the image is processed to obtain the lane line equation.

D. Binocular camera obtains the lane line equation

On the lane line, as shown in figure 4, the use of binocular camera as the sensor, the real-time processing of image data collected, for image preprocessing to remove interference part of the image, to extract the lane line information, carries on the lane line fitting, will eventually get the lane line equation, this equation is installed on the car body of binocular camera as a coordinate system, the lane line equation of relative to the body.

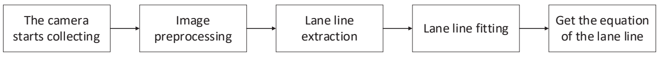


Figure. 4 Steps of obtaining lane line equation with binocular camera

E. System Scheme Design

Taking binocular camera as sensor, using binocular camera parallax principle to obtain depth data and binocular camera image processing to obtain lane line equation, this paper proposes an AGV navigation system based on binocular camera. The system consists of three parts: perception layer, decision layer and executive layer.As shown in Fig. 5, the perception layer is mainly responsible for the perception of the external environment, state and position of the vehicle body;Decision-making layer is mainly used to deal with vehicle attitude analysis, path tracking algorithm solution, vehicle safety analysis and other problems;The executive layer is mainly responsible for receiving the execution orders, and then the execution is carried out by the wire-controlled oil gate, wire-controlled steering and wire-controlled movement.

The perceptual layer, the decision layer and the executive layer cooperate with each other to form a binocular vision AGV navigation system.

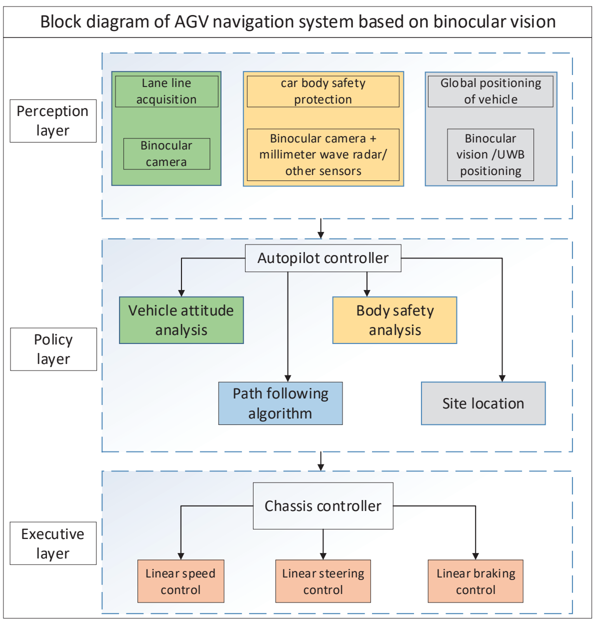


Figure. 5. Block diagram of AGV navigation system based on binocular vision

III. SOFTWARE ALGORITHM DESIGN

A. Design of vehicle pose extraction algorithm

Fig. 6 shows the acquisition algorithm of lateral deviation and course Angle deviation of the AGV navigation system based on binocular vision:

(1) After the binocular camera gets the lane line information and sends it to the automatic driving controller, in order to obtain the pose information of the vehicle body relative to the lane line, the lane line information needs to be converted into the lateral deviation and course Angle deviation of the vehicle body from the lane line, so as to facilitate the subsequent path tracking algorithm analysis.

(2) For the convenience of explanation, the lane line equation is set in the form of the commonly used cubic equation y=ax3+bx2+cx+d. The equations applied in engineering include but are not limited to the cubic equation, then the lateral deviation of the vehicle body from the lane line is:

$$\mathrm{Xt} = -\frac{d}{c} * \sin(\theta) \tag{5}$$

(3) The heading Angle deviation between the vehicle body and the lane line is:

$$\theta t = 90 - \theta \tag{6}$$

(4) Through the above calculation, the lateral deviation and course Angle deviation of the vehicle body relative to the lane line are obtained, which provides a foundation for the next step of path tracking solution.

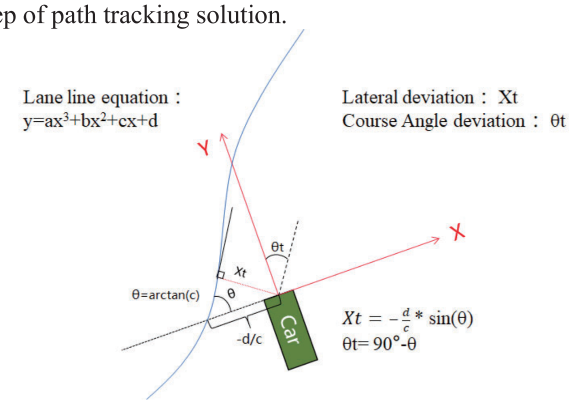


Figure. 6 Analytic diagram of vehicle pose extraction algorithm

B. Path tracing algorithm and program design

In the car body posture information relative to the lane line (including the lateral deviation error, course Angle deviation) after, need to parse path tracking algorithm, body path tracking algorithm is based on the deviation of vehicle relative to the lane line for calculating, the purpose is to eliminate the lateral deviation error vehicle relative to the lane line and course Angle deviation, the idea of path tracking algorithm are as follows:

(1) In the process of vehicle tracking along the lane line, the vehicle body will always deviate from the lane line, which is only a matter of large or small degree of deviation. Assuming that the initial process of deviation is large, the vehicle will have lateral deviation and course Angle deviation from the lane line.

(2) After the automatic driving controller obtains the current lateral deviation and course Angle deviation, it uses the path tracking algorithm to make the vehicle approach the lane line, thus reducing the lateral deviation and course Angle deviation;

(3) when the car body and the lane line and course Angle deviation for the lateral deviation error decreases to a certain value, the bodywork and stable operation, but because of the change in the lane line and the car body running change, lateral deviation error and the heading Angle deviation is changing, at this point, the path tracking algorithm has been in operation

adjustment, the vehicle running along the lane line do meet the precision of the track movement;

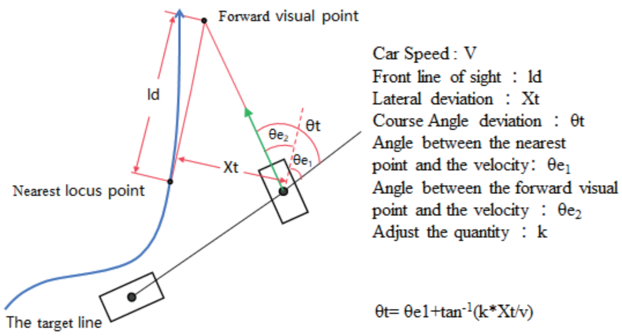


Figure 7 Stanley path tracking algorithm

Figure 7 shows the Stanley path tracking algorithm [11] in the lane line path tracking algorithm:

Stanley path tracking algorithm is an algorithm that takes the center of the front axle of the vehicle as the reference point for calculation, and its specific process is as follows:

(1) Without considering the lateral tracking error, the front wheel deflection Angle is consistent with the tangent direction of the given path, and its rotation Angle should be:

$$\theta t = \theta e1 \tag{7}$$

(2) Without considering the heading tracking deviation, the larger the lateral tracking error, the larger the front wheel steering Angle:

$$\theta t = \theta e2 = \tan^{-1}\frac{kXt}{v} \tag{8}$$

(3) After comprehensively considering the feedback of course tracking and the feedforward of lateral tracking, the front wheel rotation Angle should be:

$$\theta t = \theta e1 + \theta e2 = \theta e1 + \tan^{-1}\frac{kXt}{v} \tag{9}$$

(4) The obtained θt is the vehicle heading Angle deviation calculated by Stanley path tracking algorithm under the vehicle current deviation.

C. Path tracking program flow design

After have tasks distributed, get the vehicle position deviation, it is concluded that the recent trajectory point and the Angle between the direction of vehicle speed and former viewpoints and the Angle between the direction of vehicle speed, into the Stanley path tracking model of front wheel Angle calculation, it is concluded that the front wheel Angle, issued to the chassis controller, wire control execution, the specific process as shown in figure 8.

D. Control System program flow chart design

After hardware design and software algorithm design, the workflow of the whole system is designed, as shown in Figure 9.

(1) When there is material to be transported, the operator will use the remote scheduling management system to issue tasks to the AGV. At the same time, the current status of the vehicle can also be viewed in real time on the remote scheduling management system.

(2) After the automatic driving controller receives the assigned task, it will analyze the vehicle task and arrange the execution sequence according to the station.

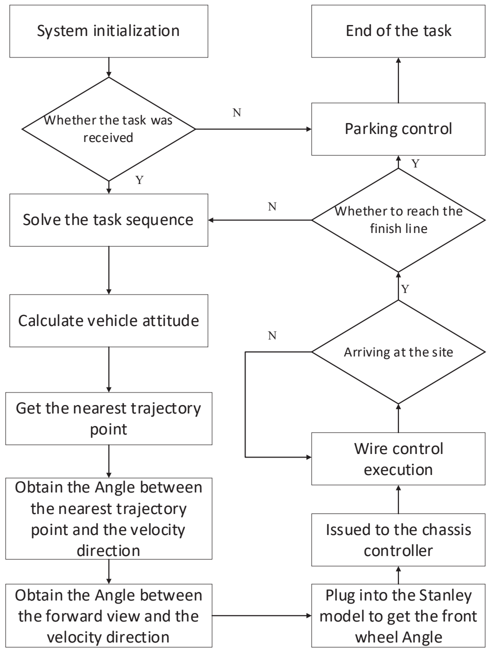


Figure. 8 Path tracing program design flow chart

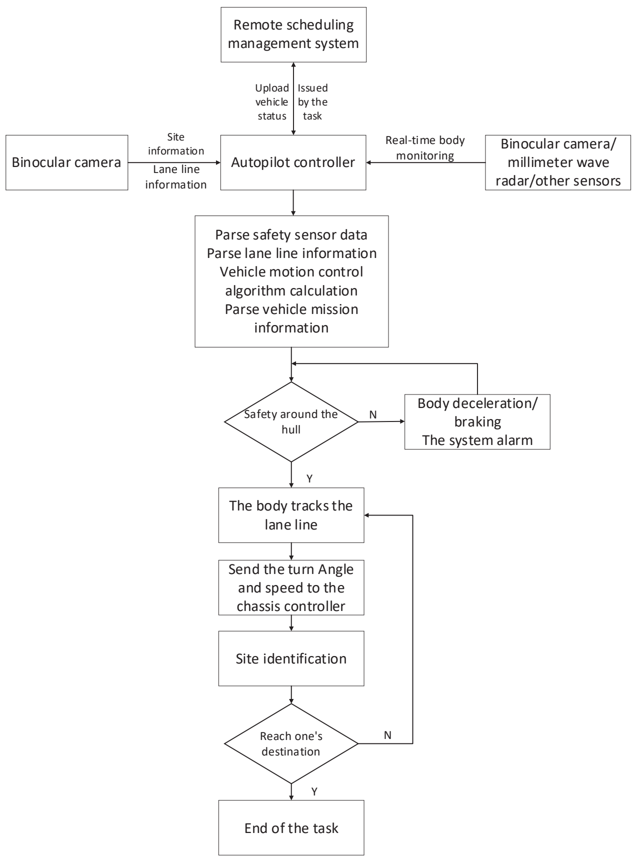


Figure. 9 Working flow chart of AGV navigation system based on binocular vision

At this time, the lane line data output by the binocular camera is processed into lateral deviation and course Angle deviation, and the automatic driving controller will analyze the lateral deviation and course Angle deviation through the path tracking algorithm to obtain the vehicle's Angle and speed.

At the same time, the data from the safety sensor of the car body is analyzed by the automatic driving controller to confirm that it is suitable to move around the car body, and the vehicle will be started to track along the lane line.

(3) In the process of movement, the safety sensor of the car body will monitor the state around the car body in real time. If there is danger, the automatic driving controller will take corresponding measures according to the danger degree, such as decelerating or braking sharply.

(4) During the operation of the vehicle, the binoculars will detect the station sign in real time to confirm their position on the global map. If they fail to reach the destination, they will continue the execution; if they reach the destination, they will slow down and stop, and the vehicle will upload the arrival information to the system to complete the task.

IV. EXPERIMENTAL DATA ANALYSIS

After the above steps, a test platform was built with a binocular camera to verify the vehicle pose data.

The experiment is divided into two parts: vehicle lateral deviation experiment and vehicle heading Angle deviation experiment.

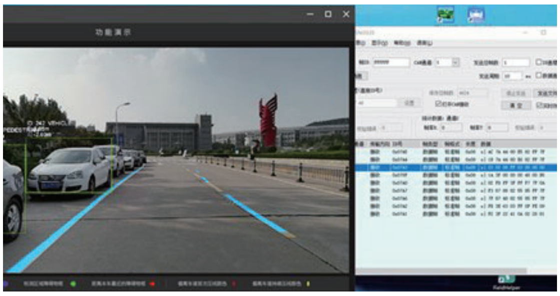


Figure. 10 Transverse deviation test diagram

First of all, vehicle lateral deviation experiment was carried out, as shown in Figure 10. The purpose of the experiment was to observe whether the data collected by the binocular camera had a corresponding relationship with the lateral deviation of the vehicle from the lane line. The test steps were as follows:

(1) Place the test platform in the direction parallel to the lane line, and make a mark on the ground every 10cm in the horizontal direction of this position;

(2) At the first marked position, the lateral distance between the current position and the lane line and the lane line equation data are collected.

(3) All markers were collected successively, and repeated measurements were made several times, and then data analysis was performed.

The collected data are analyzed, as shown in Table 1 and Figure 11. It can be seen that the lateral deviation between the car body and the lane line is in a linear relationship with the data collected by the binocular camera.

According to this relation, the lateral deviation relation between the vehicle body and the lane line can be reflected according to the y-intercept in the equation.

Table 1 Statistical results of lateral deviation

Set the distance (cm)	X intercept	Y intercept	Lateral deviation
40	-10.0533	32.332	0
50	-9.9665	32.276	0.056
60	-9.972	32.202	0.13
70	-9.9	32.102	0.23
80	-9.81	31.998	0.334
90	-9.6947	31.915	0.417
100	-9.6575	31.828	0.504
110	-9.63168	31.727	0.605
120	-9.7388	31.683	0.649
130	-9.71839	31.548	0.784
140	-9.7138	31.442	0.89
150	-9.6045	31.36	0.972
160	-9.507	31.257	1.075

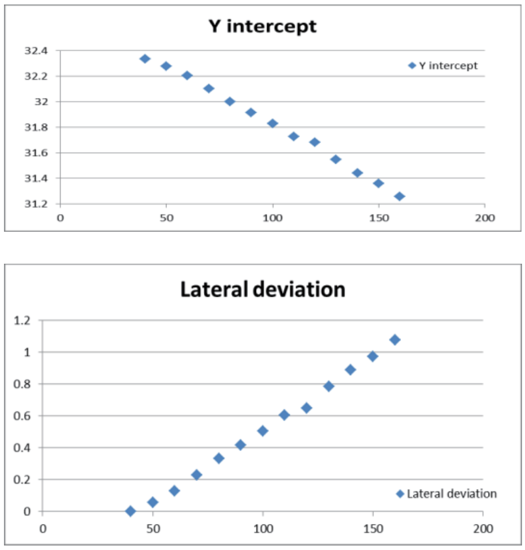


Figure. 11 Trend line of lateral deviation data

Figure. 12 heading Angle deviation test diagram

Secondly, the heading Angle deviation test experiment is carried out, as shown in Figure 12. The purpose of the experiment is to observe whether the data collected by the binocular camera corresponds to the rotation Angle of the vehicle and the lane line. The test steps are as follows:

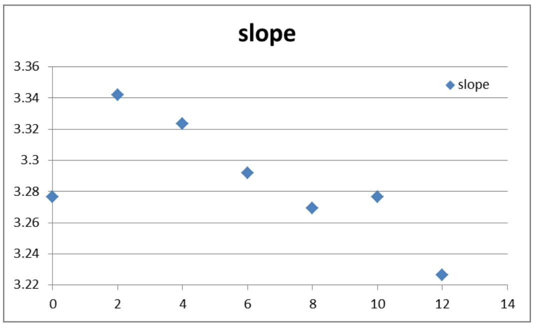
(1) Place the test platform at a distance parallel to the lane line and make a mark on the ground;

(2) In the marking position, determine the Angle, and record the set Angle value and the Angle value collected by the binocular camera.

(3) Collect all Angle values successively, and repeat the measurement several times, and then do data analysis.

Table 2 Statistical results of heading Angle deviation

Offset Angle	Measured Angle	slope	Course Angle deviation
0	73.0285933	3.2767	
2	73.3421309	3.3421	-0.3135376
4	73.2531595	3.3233	-0.2245662
6	73.1034501	3.2921	-0.0748569
8	72.993374	3.2695	0.03521929
10	73.0285933	3.2767	0
12	72.7800483	3.2265	0.24854497



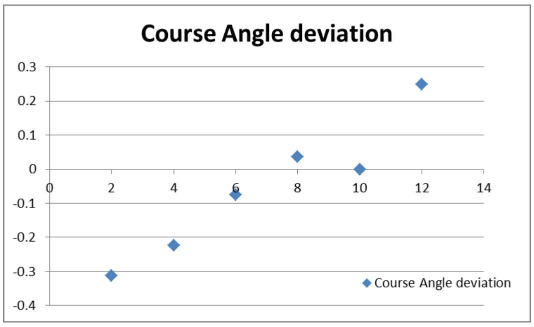


Figure. 13 Trend line of heading Angle deviation test data

The collected data are analyzed, as shown in Table 2 and Figure 13. It can be seen that the heading Angle deviation between the vehicle body and the lane line has a linear relationship with the data collected by the binocular camera, and abnormal interference points can be filtered out by the algorithm.

According to this linear relationship, the course Angle deviation relationship between the vehicle body and the lane line can be reflected by obtaining the slope in the equation.

V. Conclusion

AGV uses binocular camera as sensor, the vehicle lateral deviation and course Angle deviation obtained by the binocular camera provide the basis for the vehicle automatic driving.Through the forward obstacle avoidance detection function of binocular camera, it can also provide the safety protection function for the vehicle.Through real vehicle experiments, it is verified that the control system in this paper has good stability and repeated positioning accuracy, and can meet the navigation requirements of the AGV in the complex route of indoor and outdoor operation, which has important significance for the realization of automation and intellectualization of factory handling.

References

[1] Namita Singh,P. V. Sarngadharan,Prabir K. Pal. AGV scheduling for automated material distribution: a case study[J]. Journal of Intelligent Manufacturing,2011,22(2).

[2] V Venkataramanan M A . A Branch-and Bound Algorithm for Flow-Path Design of Automated Guided Vehicle Systems[J]. Naval Research Logistics, 2015, 38(3): 431-445.

[3] Stentz A, BarcsJ, Singh S, ct al. A robotic excavator for autonomous truck loading[J]. Autonomous Robots, 1999, 7(2):175- 186

[4] Jiangtao Wang. Research on Visual Navigation of Autonomous Vehicle Based on PMAC [D]. Qingdao: Qingdao University,2005.

[5] Jiajie Yao. Vision-based Road Detection and Navigation for AGV systems [D]. Hangzhou: Zhejiang University,,2014.

[6] Jinchao Li Vision-Based Automatic tracking AGV control system design [D]. Qinhuangdao: Yanshan University,2014.

[7] Wan Hao. Research on Vehicle System of AGV Based on Visual Navigation [D]. Nanchang: Nanchang Hangkong University,2014.

[8] Ruizhu Nie. Research on AGV path tracking technology based on vision [D]. Qingdao: Qingdao University of Science & Technology,2015.

[9] Weiliang Shen. Research on the key technology of intelligent fault tolerance in vision guidance system of AGV [D]. Nanjing: Nanjing University Of Aeronautics And Astronautics,2016.

[10] Qiangwei Huang. Research on Binocular Vision Ranging and Aiming Attitude Solving Algorithms for Mobile Robots [D].Nanchang: Nanchang University,2020.

[11] Sebastian Thrun,Mike Montemerlo,Hendrik Dahlkamp,David Stavens,Andrei Aron,James Diebel,Philip Fong,John Gale,Morgan Halpenny,Gabriel Hoffmann,Kenny Lau,Celia Oakley,Mark Palatucci,Vaughan Pratt,Pascal Stang,Sven Strohband,Cedric Dupont,Lars-Erik Jendrossek,Christian Koelen,Charles Markey,Carlo Rummel,Joe van Niekerk,Eric Jensen,Philippe Alessandrini,Gary Bradski,Bob Davies,Scott Ettinger,Adrian Kaehler,Ara Nefian,Pamela Mahoney. Stanley: The robot that won the DARPA Grand Challenge[J]. Journal of Field Robotics,2006,23(9).