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Design of Four Wheel Drive Four Wheel Steering AGV And Trajectory Tracking Control Research

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Abstract—**A four-wheel independent driving and four-wheel independent steering platforms is present in this paper. Compared with the Mecanum wheel, it has the advantages of simple processing, high motion efficiency, strong bearing capacity, and can adapt to complex factory conditions. Firstly, the omnidirectional kinematics model is constructed, and the kinematics analysis is carried out to obtain the relationship between the rotational speed and the rotation angle under different steering modes. Secondly, in order to realize the trajectory tracking control of omnidirectional mobile platform, the lateral deviation trajectory tracking control algorithm of omnidirectional mobile platform is proposed. In order to achieve accurate trajectory tracking and provide sufficient corrective ability for trajectory tracking, a hierarchical control strategy is proposed. Finally, the actual vehicle experiment proves that the full steering mobile platform has good motion effect and can meet the requirements of working conditions, which provides a certain reference for the application of AGV in the industrial field.**

***Index Terms*—4WD4WS; omnidirectional kinematics model; trajectory tracking; hierarchical control.**

I. INTRODUCTION

With the rapid development of China's manufacturing industry and the "Made in China 2025", its automation plant faces enormous challenges. Automated Guided Vehicle (AGV) is an important part of the realization of factory automation, and plays a significant role in the logistics industry and the warehousing industry [1]. At present, the guide wheels of the all-round AGV mostly use the Mecanum wheel or the spherical wheel [2-3]. Due to its own structural characteristics, it will produce vibration, slip, lack of motion stability, and low control precision [4]. In order to overcome these shortcomings, a new all-steering mechanism based on hub motor is designed, which has multiple steering modes such as straight, horizontal, four-wheel steering, four-wheel steering and zero-radius steering, which can be flexible in a small space. Free movement and carrying different types of handling robots to meet industrial production requirements.

II. 4WD4WS MOBILE PLATFORM DESIGN

The omnidirectional platform is based on four-wheel independent line controlling steering and driving. The guiding mechanism is mainly composed of the driving wheel of the hub motor, the steering motor, the steering reducer, the steering gear, the electromagnetic brake, the base bracket and the like. When the steering is turned, the steering pinion rotates around the steering gear fixed on the frame to achieve a steering angle of positive and negative ninety degrees, while eliminating the traditional steering rod mechanism and improving the steering stability. The guiding mechanism adopts electromagnetic braking, integrated into the brake shaft of the hub motor, improves the positioning accuracy of the mobile platform. The hub motor and the steering motor are respectively equipped with a speed encoder and a corner encoder for real-time detection and feedback of speed and rotation angle. The structure of the steering wheel assembly is shown in Figure.1.

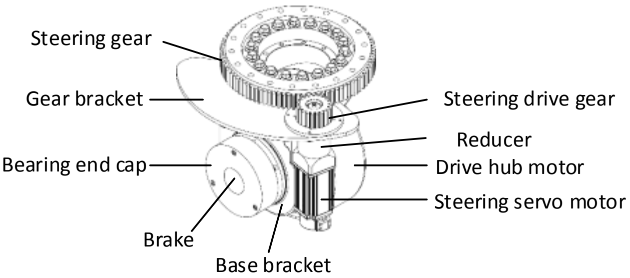

Fig.1 Steering and drive wheel assembly structure

III. 4WD4WS KINEMATICS MODEL

The omnidirectional mobile platform tires use rigid wheels, which have the advantages of fast response, no vibration, and good wear resistance compared to conventional rubber tires. The applicable occasions of the mobile platform are mainly special occasions such as workshop transportation and express transportation [5] .The omnidirectional mobile platform has been working at medium and low speeds. The steering mechanism is fastened to the frame, and there is no suspension structure and mechanical transmission mechanism. It can be considered that the omnidirectional mobile platform will not produce side deflection. Movement and pitching movements. It is assumed that only the rolling does not cause slippage during the movement of the omnidirectional mobile platform, and thus an omnidirectional kinematics model based on 4WID-4WIS is obtained. The four-wheel steering automatic guided vehicle system is shown in Figure.2.

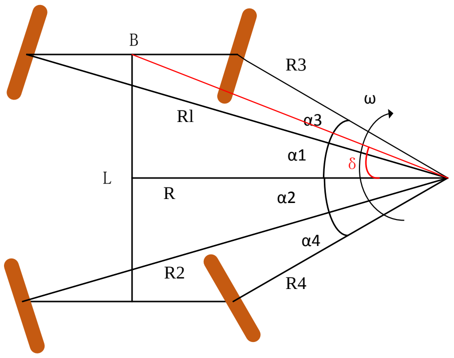

Figure.2 Schematic diagram of four-wheel steering

A. Kinematic Model In Four-Wheel Steering Mode

When the given steering reference angle of the lidar navigation is δ, and the reference speed of the drive is V, the steering radius of the omnidirectional mobile platform can be obtained as follows:

$$R = \frac{L}{2\tan\delta} \tag{1}$$

Where L is the wheelbase of the vehicle.

From this, it can be concluded that the turning radii of the left and right wheels are respectively $R_i \ (i = 1,2,3,4)$:

$$\begin{aligned} R_i &= \frac{L}{2\tan\delta} + \frac{B}{2}(\mathrm{i}=1,2) \\ R_j &= \frac{L}{2\tan\delta} - \frac{B}{2}(\mathrm{j}=3,4) \end{aligned} \tag{2}$$

Where B is the track between the left and right wheels.

According to equations (1) and (2), the angles of the individual wheels can be derived:

$$\alpha_{\mathrm{i}} = \arctan\left(\frac{L}{2}/(R+\frac{B}{2})\right),(i=1,2) \tag{3}$$

$$\alpha_j = \arctan\left(\frac{L}{2}/(R-\frac{B}{2})\right),(j=3,4) \tag{4}$$

Based on the given speed, the speeds of the four wheels are:

$$v_i = \frac{v}{R} \times R_i, (\mathrm{i}=1,2,3,4) \tag{5}$$

B. Mathematical Model of Zero Radius Steering And Lateral Driving

When the omnidirectional mobile platform is turned in place, that is, turning around the geometric center point of the platform, the relationship between the four wheel corners and the speed is:

$$\begin{aligned} \alpha_1 &= \alpha_4 = -\arctan\left(\frac{L}{B}\right) \\ \alpha_2 &= \alpha_3 = \arctan\left(\frac{L}{B}\right) \end{aligned} \tag{6}$$

$$v_1 = v_2 = v_3 = v_4 \tag{7}$$

The four wheel angles are 90^{o} when driving in landscape direction. The speed values are:.

$$v_1 = v_2 = v_3 = v_4 \tag{8}$$

IV. 4WD4WS MOBILE PLATFORM MOTION CONTROL STRATEGY

The designed omnidirectional mobile platform PC control is based on the lidar navigation system. When it issues motion commands, according to the established omnidirectional motion algorithm, each wheel of the omnidirectional AGV will have a corresponding corner and speed. In order to achieve fast and accurate trajectory deviation of the omnidirectional AGV, this paper proposes a lateral lag control algorithm to achieve accurate trajectory tracking control of omnidirectional AGV. In order to achieve high-precision trajectory tracking control, this paper adopts a control algorithm that comprehensively considers lateral deviation and heading deviation.

Firstly, according to the upper-layer lidar real-time feedback of the current position of the vehicle, the target waypoint is searched. Secondly, the preview distance is determined based on the conditions such as the curvature of the lane. The relationship between the preview distance and the vehicle speed is determined by the segmentation idea. Finally, the vehicle is determined according to the mathematical relationship. The transfer function relationship between the steering wheel angle and the preview error, and the control output is corrected in real time through the feedback system. The structural diagram of the algorithm for lateral deviation is shown in Figure.3.

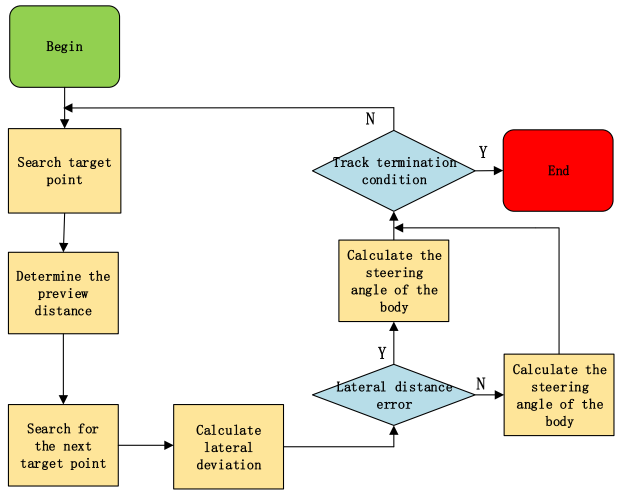

Figure.3 The structure of the algorithm for lateral deviation

At present, there is less research on the underlying motor control of omnidirectional mobile platforms [6], and most of them focus on the design of the underlying circuit. The omnidirectional mobile platform developed by the company uses the two parts of the steering motor and the hub motor to drive at the same time. The two can operate at the same time to realize the motion control. According to the upper control algorithm, there is a mathematical relationship between the driving speed and the steering angle. When the road conditions are more complicated, the control accuracy of the two motors will be affected, and the control coupling will occur between the two motors. Accuracy and sufficient corrective ability for path tracking control, underlying layered control between steering motor and hub motor [7]. In this paper, the decoupling idea of the reference model [8] is used to design a hierarchical controller between two motors.

A. Kinematics Model of Lateral Deviation

Because the omnidirectional AGV studied in this paper is a symmetrical structure, and the rotation angles of the front and rear wheels are equal and opposite in direction, the turning process of the four-wheel omnidirectional AGV is simplified to the bicycle model with the opposite front and rear wheel angles. The kinematic model of the omnidirectional AGV is shown in the Figure.4:

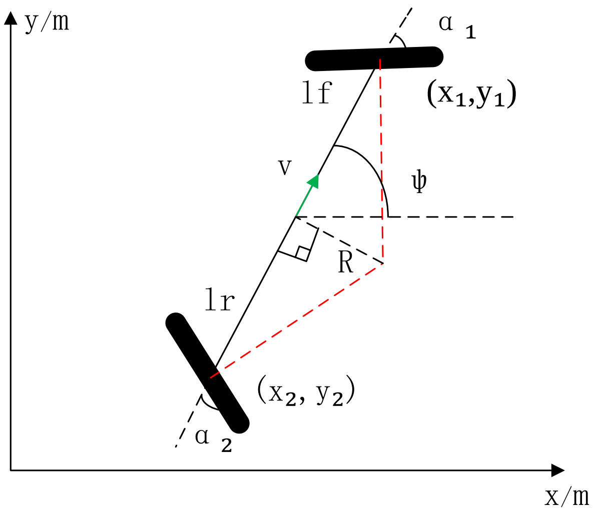

Figure.4 The kinematic model of the omnidirectional AGV

In the global coordinate system X-O-Y, it (x_1, y_1) is the center coordinate of the front axis of the AGV, which (x_2, y_2) is the center coordinate of the rear axis of the AGV, and it (x, y) is the coordinate of the centroid of the AGV. For the front wheel steering angle is α_1, the rear wheel steering angle is α_2, the angle between the car body and the horizontal coordinate axis x is φ,which is the heading angle of the car, l_f is the wheelbase length of the front half of the AGV body, and l_r is the wheelbase of the rear half of the AGV body Length, the total wheelbase length of the car body is $l = l_f + l_r$, and R is the turning radius of the AGV. The AGV studied in this paper is an automatic guided vehicle for warehousing and freight transportation. Due to the limitation of the operating environment, the speed of the AGV is very small. Most of the body of the AGV is a rigid body structure. In this paper, it is assumed here that the car body has no sideways and the motion of the AGV is pure rolling.

The horizontal component of the velocity at the center of mass is:

$$\dot{x} = v\cos\varphi \tag{9}$$

The vertical component of the velocity at the center of mass is:

$$\dot{y} = v\sin\varphi \tag{10}$$

Through the geometric relationship we can get:

$$\frac{\sin\alpha_1}{l_f} = \frac{\cos\alpha_1}{R} \tag{11}$$

$$\frac{\sin\alpha_2}{l_r} = \frac{\cos\alpha_2}{R} \tag{12}$$

From the above four formulas (9-12) we can get:

$$\tan\alpha_1 + \tan\alpha_2 = \frac{l}{R} \tag{13}$$

The angular velocity of the AGV turn is

$$\omega = \dot{\varphi} = \frac{2\tan\alpha_1}{l}v \tag{14}$$

The final kinematics equation for AGV is as follows:

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\varphi} \end{bmatrix} = \begin{bmatrix} \cos\varphi \\ \sin\varphi \\ 2\tan\alpha_1 / l \end{bmatrix} v \tag{15}$$

B. Trajectory Tracking Controller Design

For the driverless control system studied in this paper, the control volume is mainly front wheel angle and longitudinal speed. The control system of the self-driving car is one typical delay, nonlinear unstable system, and pre-control control action obviously predictable, which is significantly better than traditional relying on information feedback control algorithm for generating control actions.

The preview distance directly affects the accuracy of the path tracking, and its selection is to important [8]. Smaller preview distance allows the vehicle to track the path more accurately and track the path of greater curvature; the larger pre-sight distance can be reduced the overshoot of the vehicle during the tracking process and improve the smoothness of the tracking. The relationship between the preview distance and the longitudinal speed of the vehicle is represents in equation 1:

$$\rho = \begin{cases} av + l_{\min}, 0 \le v \le (l_{\max} - l_{\min})/a \\ l_{\max}, v \ge (l_{\max} - l_{\min})/a \end{cases} \tag{16}$$

In the formula, $l_{\min}$ and $l_{\max}$ are the minimum and maximum preview distances respectively; a is a constant.

The trajectory tracking method based on Pure Pursuit is a geometric method The method is widely used in trajectory tracking control of robots [12]. The algorithm The midpoint of the rear axle of the vehicle is the tangent point, and the longitudinal symmetry axis of the vehicle is tangent. By calculating the front wheel yaw α_1 and the geometric relationship of the deviation angle, so that the vehicle can pass along The arc of the preview point travels, and the preview deviation angle also follows in this process. As shown in Figure.5.

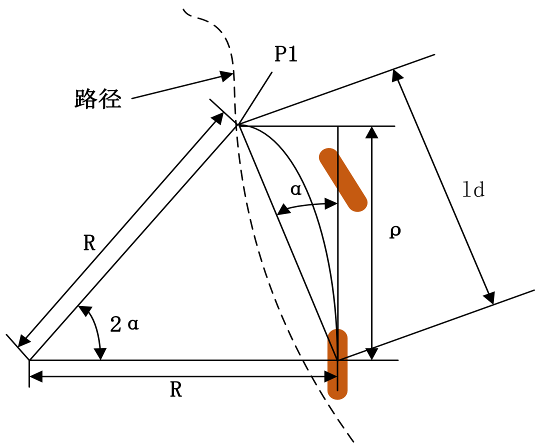

Figure.5 The tracking diagram of omnidirectional AGV

Available from the sine theory:

$$\frac{l_d}{\sin(2\alpha)} = \frac{R}{\sin(\frac{\pi}{2} - \alpha)} \tag{17}$$

$$k = \frac{2\sin\alpha}{l_d} \tag{18}$$

Where l_d is the distance between the current position and the pre-pump point P1; κ is the arc curvature

According to the simplified Ackerman vehicle model, the front wheel angle α can be expressed as:

$$\alpha_1 = \arctan \frac{2L\sin\alpha}{l_d} \tag{19}$$

According to the kinematic model, the speed and corner of the four wheels can be obtained.

C. *Design of the Underlying Vehicle Controller*

According to the above analysis, the control amount of the omnidirectional AGV can be obtained by the kinematic model and the four-wheel steering model. Reflected on the four-wheel independent control platform is the corner and speed. This paper establishes the model of the four-wheel steering using the C code to write into the vehicle controller according to the idea of hierarchical control. The control structure diagram are shown in the Figure.6:

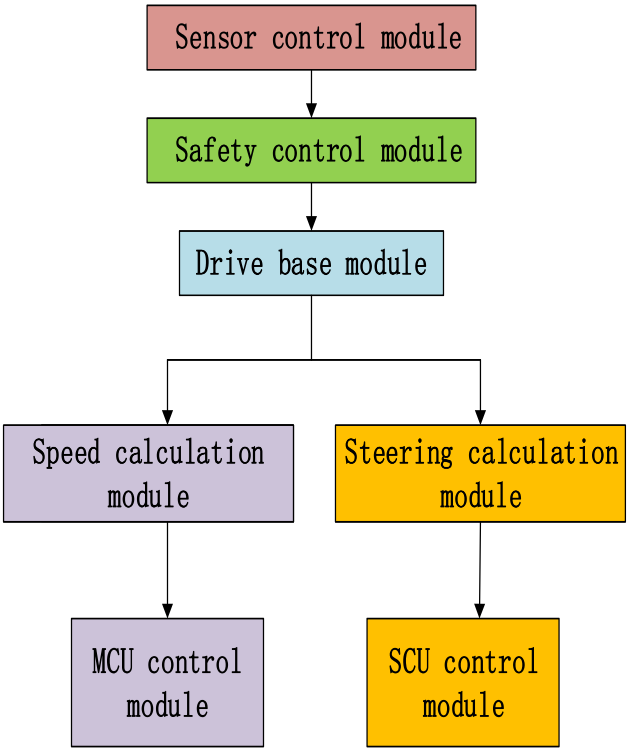

Figure.6 The structure of vehicle control system

V. Experiments and Analysis:

In order to verify the effectiveness of its motion control strategy and the reliability of the motion, the prototype of the developed prototype was tested.

The center wheelbase of the platform is 1420mm, the wheelbase between the two cars is 1026mm, and its motion control mode is four-wheel independent steering and four-wheel independent driving. The vehicle laser radar system is installed above the vehicle body, and the main motion controller adopts autonomous. Embedded systems developed. the physical map of the whole vehicle are shown in Figures.7.

Figure.7 The omnidirectional AGV

We perform straight, oblique, traverse, zero-radius in-situ steering experiments for stratified joint-controlled steering and hub motors. The parameters of the steering control are shown in the following Table.1:

Table.1: The steering angle of 4WD4WS system

variable / type	α_1	α_2	α_3	α_4
straight	0^o	0^o	0^o	0^o
traverse	90^o	90^o	90^o	90^o
zero-radius	57.3^o	-57.3^o	-57.3^o	57.3^o

The parameters of the speed control are shown in the following Table.2:

Table.2: The speed of 4WD4WS system

variable / type	v_1	v_2	v_3	v_4
straight	$30rpm$	$30rpm$	$30rpm$	$30rpm$
traverse	$30rpm$	$30rpm$	$30rpm$	$30rpm$
zero-radius	$30rpm$	$30rpm$	$-30rpm$	$-30rpm$

We carried out experiments on the automatic guided vehicles that drive the servo motor of the hub motor to go straight, oblique, horizontal, in-situ, and self-tracking under five working conditions. The data is shown in Figure.8 and Figure.9.

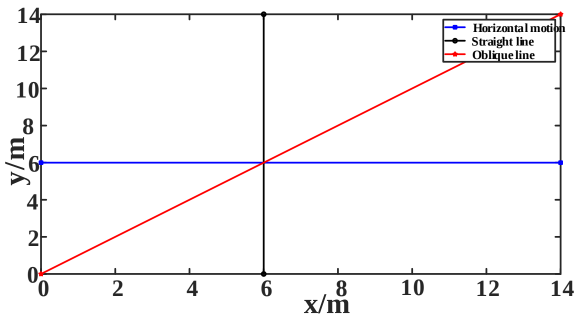

Figure.8 The experimental test for motion controling

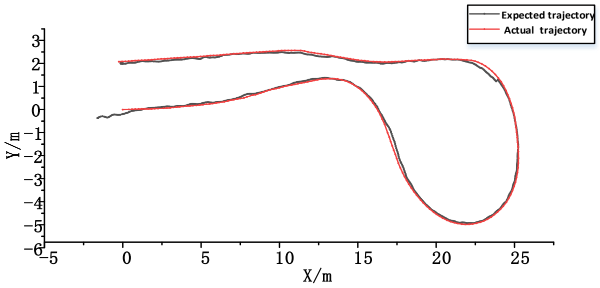

Figure.9 The experimental test for trajectory tracking

Through experimental data analysis, it can be concluded that the motor can provide a good output response, and the error between the rotation angle and the rotation speed is also within the ideal control range. In the case of deviation, the path tracking has good rectification ability.

VI. Conclusion

1) This paper designs a new automatic guided vehicle based on four-wheel drive four-wheel independent steering driven by hub motor, which can make straight-line, oblique, horizontal, in-situ steering and autonomous tracking of omnidirectional mobile platforms. Driving under different working conditions; based on the 4WID-4WIS control method, the omnidirectional kinematics model was established and kinematics analysis was carried out.
2) In this paper, a trajectory tracking algorithm for lateral deviation is designed for the omnidirectional mobile platform. The joint control between the steering motor and the hub motor is realized by the layered control strategy, which has good input and output response and ensures the control precision.
3) The experiment in this paper verifies that the omnidirectional moving platform has good motion effect, meets the requirements of industrial use, and provides some reference for the application in the industrial field.

References

[1] X Wu, P H Lou, J Yu, et al, Intersection recognition and guide-path selection for a vision-based AGV in a bidirectional flow network [J]. International Journal of Advanced Robotic Systems, 2014, pp.1-17.
[2] S G Wang. Principles and design of mobile robots [M]. Beijing: People's Posts and Telecommunications Press, 2013 pp. 32-38. H.
[3] W Tang, Y Liu, H X Hu, et al. Kinematics Analysis and Self-adaptive Controller Design of Omni-directional Movement Platform [J]. Mechanical Science and Technology for Aerospace Engineering, 2016, pp. 883-889..
[4] C Gosselin, J Angeles, Singularity analysis of closed-loop kinematic chains [J]. IEEE Transactions on Robotics and Automations, 1990, pp. 281-290.
[5] Y P Li. Slip modelling estimation and control of omnidirectional wheel mobile robots with powered caster wheel [D], Singapore: National University of Singapore, Department of Mechanical Engineering, 2009, pp. 5-15.
[6] X Wu, P H Lou, D B Tang. Integrated Motion Control of Path Tracking and Servo Control for an Automated Guided Vehicle [J]. Chinese Journal of Mechanical Engineering, 2011, pp. 43-48.
[7] T X Yang, P H Lou, X M Qian. Path tracking control technology of omnidirectional mobile AGV combined with multiple fuzzy controllers [J]. 2016, pp. 57-61.
[8] A J Prado, Michalek F, A, Cheein, et al. Machine learning based approaches for self tuning trajectory tracking controllersunder terrain changes in repetitive tasks[J].Engineering Applications of Artificial Intelligence, 2018, pp. 63-80

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