

# Design and Implementation of Control System for Submersible AGV

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**Abstract:** In this essay, a PID trajectory tracking algorithm combining the lateral position with the yaw Angle is proposed, which is also implemented in the insert AGV control system, so as to meet the demand of a certain automobile manufacturer in the outdoor use of AGV to automatically move new cars rolling off the assembly line to the parking lot. According to the positioning information of RTK-GPS, the AGV control system takes the vehicle-mounted coordinate system as the control reference and uses the PID algorithm combining the lateral position and yaw Angle, thus realizing the trajectory tracking. Through numerous tests of real vehicles under various environments, the positioning accuracy and orientation accuracy of AGV in the process of picking up the vehicle reach  $\pm 25\text{mm}$  and  $\pm 0.1^\circ$  respectively. Being deployed in the AGV trailer, the control algorithm with the dispatch of the scheduling system can take fixed-point pickup, track tracking, vehicle release and other actions, and can run for a long time with high precision and stability.

**Keywords:** PID algorithm; RTK-GPS; AGV control system

## 1. Introduction

China owns the biggest automobile market in the world and is regarded as the biggest automobile manufacturing country. From the perspective of cost reduction, the realization of automatic and unmanned operation in the process of production and manufacturing becomes the pursuit of automobile manufacturing enterprises.

AGV (Automated Guided Vehicle) car usually refers to a transport vehicle equipped with automatic guided devices such as electromagnetic, vision<sup>[1]</sup>, Lidar<sup>[2]</sup> and GPS which enable the vehicle to run along the specified guided path and had safety protection and various load shifting functions. The world's first AGV was successfully developed by an American company Basrret Electronics Company<sup>[3]</sup> in 1953 while the first AGV appeared in China was developed by Beijing Lifting Machinery Research Institute in 1976<sup>[4]</sup>. Furthermore, in 1991, Shenyang Institute of Automation, Chinese Academy of Sciences completed the transformation of AGV from laboratory prototype to front-line production products through the Jinbei Assembly project. At present, AGV has been widely used in indoor logistics and transportation of automobile manufacturers<sup>[5-9]</sup>, but the heavy-load AGV that can automatically transfer new cars rolling off the assembly line to parking lots outdoors has not been reported in China yet.

Thus, an insert AGV control system is developed to meet the needs of an automobile manufacturer to automatically transfer new cars rolling off the assembly line to parking lots outdoors. Usually, the methods of embedded magnetic nails or two-dimensional code tracking based on visual recognition are adopted to help the AGV control system achieve high enough control accuracy in trajectory tracking<sup>[10-11]</sup>. But when the control system of the AGV used in large outdoor areas is doing track tracking with GPS positioning and navigation, centimeter-level control accuracy for track tracking is unnecessary in most cases.

In this essay, a track tracking control algorithm of Ackerman angular heavy-load AGV used in outdoor is introduced, utilizing RTK-GPS to locate the vehicle and achieve centimeter-level operation accuracy. The specific requirements of the task are as follows: during the whole process of reversing into the bottom of the new car, the AGV chassis position error is required to be less than  $\pm 25\text{mm}$  and yaw Angle error is required to be less than  $\pm 0.1^\circ$ , and it needs to run stably for a long time in different environments.

## 2. Design of AGV Control System

In this chapter, the AGV control system as a whole is introduced as a whole first before deducing the PID algorithm with the combination of lateral position and yaw Angle in detail.

### 2.1. Overall Design of the Control System

The AGV control system is the vehicle brain that is under the operational control of insert AGV, which is made up by the vehicle motion control system and IO extension system, realizing the functions of control, collection, management, and etc of other vehicle systems like the battery system, hydraulic system, driving system, GPS system, security collision avoidance system, dispatching system and background monitoring system, remote control and IO signal control system. The main chip of the controller is STM32 F407, and the AGV is equipped with P2 RTK-GPS for positioning.

### 2.2. The Transformation from Terrestrial Coordinate System to Geodetic Local Coordinate System

The location information given by P2 integrated navigation system is the longitude and latitude values which need to be converted into the value of the local geodetic coordinate system. In tradition, when calculating the distance between two points of latitude and longitude, the great-circle distance formula is adopted, which requires a lot of cosine functions. However, when the distance between these two points is very short (such as a distance of a few hundred meters between two spots on the earth's surface), the result given by the cosine function will be 0.999..., which generates serious rounding errors. So, a sinusoidal algorithm to calculate the distance between two latitude and longitude points is taken into consideration so that sufficiently significant numbers can be maintained when the distance is really small. That is how the Haversine formula adopts the sine function to maintain sufficiently effective numbers even at small distances.

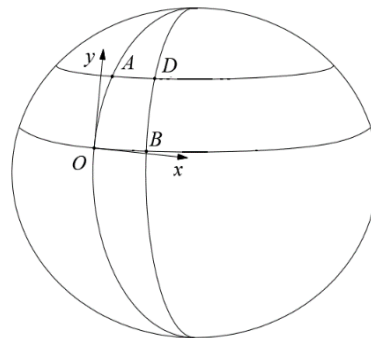


Figure 1: Simplified Terrestrial Rectangular Coordinate System

In the application process of RTK-GPS in the positioning process of AGV, a simplified calculation model is set as shown in Figure 1, in which x axis is a line along the latitude line, and y axis is a line along the longitude line. Considering that the motion range of AGV is relatively small, the latitude and longitude curves can be replaced by straight x and y axes, and the x and y axes are perpendicular to each other. In Figure 1, the values of latitude and longitude of the four points are A (lat1, lon1), B (lat2, lon2), O (lat2, lon1) and D (lat1, lon2) respectively. The rectangular coordinate system is established with point O as the origin of coordinates. In the range of the motion of AGV, the y-coordinate value of any point D can be expressed by the latitude difference between point A and point O. Similarly, the value of point D at the x coordinate can be expressed as the difference in longitude between B and O.

According to the result the Haversine formula calculating for the sine length, the coordinate values of point D in the terrestrial coordinate system shown in Figure 1 are as follows:

$$y = L_{OA} = 2R * \sin(dlat / 2) \quad (1)$$

$$x_1 = L_{OB} = 2R * \cos(lat2) * \sin(dlon / 2) \quad (2)$$

In the equation, dlat and dlon are the difference values of dimension and longitude of point D and point O respectively, and R is the radius of the Earth (the average radius of the Earth is 6371km). In this way, the local geodetic coordinate system is established at any point selected as the origin of coordinates in the AGV operating region. The coordinate value (x1, y) of the local geodetic coordinate system at any

point can be obtained according to formulas (1) and (2).

If the distance of point D from O (the origin of the coordinates), then AD is approximately equal to BO, so the x coordinate value of point D can also be expressed as:

$$x_2 = L_{AD} = 2R * \cos(\text{lat1}) * \sin(\text{dlon} / 2) \tag{3}$$

Furthermore, the length of DO is equal to the length of AB which means the distance from any point D to the origin O of the rectangular coordinate system is:

$$L_{DO} = L_{AB} = \sqrt{L_{AO}^2 + L_{BO}L_{AD}} = \sqrt{y^2 + x_1x_2} \tag{4}$$

### 2.3. The Inter-conversion of Geodetic Local Coordinate System and Vehicle-mounted Coordinate System

The origin of the vehicle-mounted coordinate system is fixed in the center of the vehicle-mounted GPS receiver. And the correction algorithm is based on the vehicle-mounted coordinate system when the AGV is controlled to walk along the predetermined path. However, the vehicle-mounted coordinate system is changing moment-to-moment. Since the trajectory planning of AGV sent by the dispatching system or the trajectory of AGV during automatic operation is given according to the geodetic local coordinate system, it is necessary to transform the geodetic local coordinate system into AGV vehicle-mounted coordinate system.

As what has been shown in Figure 2, AGV is regarded as base point  $o_1 (x_{o1}, y_{o1})$ , which is both the location of the center of vehicle-mounted GPS and the origin of the vehicle-mounted coordinate system. And the forward direction of AGV is the direction of  $x_1$  axis of the vehicle-mounted coordinate system. The angle between geodetic local coordinate system  $xoy$  and the vehicle-mounted coordinate system  $x_1o_1y_1$  is the  $\theta$  angle which is the yaw Angle of the AGV that can be sensed in real time from the IMU sensor. The position and pose state of AGV can be represented by a 3-D coordinate, in which subscript 0 is used to represent the geodetic local coordinate system.

$$\xi_0 = \begin{bmatrix} x_0 \\ y_0 \\ \theta_0 \end{bmatrix} \tag{5}$$

In order to describe the components of AGV in dynamic state, it is necessary to establish a corresponding relation between the geodetic coordinate system and the vehicle-mounted coordinate system, which can be expressed in the form of an orthogonal matrix, as shown below:

$$R(\theta) = \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

Therefore, the coordinates of the local geodetic coordinate system at point  $o_1$  after rotating an angle  $\theta$  can be expressed as:

$$\xi_1 = R(\theta)\xi_0 \tag{7}$$

Then, subscript 1 is used to represent the coordinates after rotation of  $\theta$  Angle, the equation can be further extended to:

$$\xi_1 = \begin{bmatrix} x_1 \\ y_1 \\ \theta_1 \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta & 0 \\ -\sin \theta & \cos \theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ \theta_0 \end{bmatrix} = \begin{bmatrix} x_0 \cos \theta + y_0 \sin \theta \\ -x_0 \sin \theta + y_0 \cos \theta \\ \theta \end{bmatrix} \tag{8}$$

Thus, through formula (8), rotate the local geodetic coordinate system of AGV where the base point  $o_1$  locates by an Angle (yaw Angle  $\theta$ ) to obtain a new local geodetic coordinate system whose origin is still at point  $o$  and whose  $x$  and  $y$  axes are consistent with the  $x_1$  and  $y_1$  axes of the vehicle-mounted coordinate system.

In formula (8),  $\theta_1$ ,  $\theta_0$  and  $\theta$  are equal, which means that the value of base point  $xy$  coordinate will change after rotation while the yaw Angle remains unchanged. After rotation, the new geodetic local

coordinate system will be shifted along the  $x$  and  $y$  values so that the  $x_1$  and  $y_1$  values can coincide with the vehicle-mounted coordinate system.

This part of transformation is very significant. In the follow-up trajectory tracking direction correction, the geodetic local coordinates of the aiming point will also be rotated to the same  $\theta$  Angle (real-time yaw Angle of AGV). In this way, it is only required to calculate the deviation between the  $y$  value (lateral) of the two points and the yaw Angle while the real-time yaw value can be obtained by the PID algorithm. There is no need to calculate the deviation of the  $X$  value. Since the  $x$ -axis direction is the forward direction of the vehicle, the AGV runs at a constant speed, moving to the  $X$  value of the aiming point predicatively.

Since the yaw Angle of AGV given by IMU of P2 joint navigation system is  $0^\circ$  from due north direction, clockwise rotation is the positive direction of yaw Angle. After transformation, the forward direction of the vehicle is the direction of the  $y$ -axis. In the actual PID algorithm, the deviation between the  $x$  value (lateral) and yaw Angle of the aiming point and the current point of the AGV is calculated, which is put into the PID algorithm to obtain the joint real-time deviation correction value.

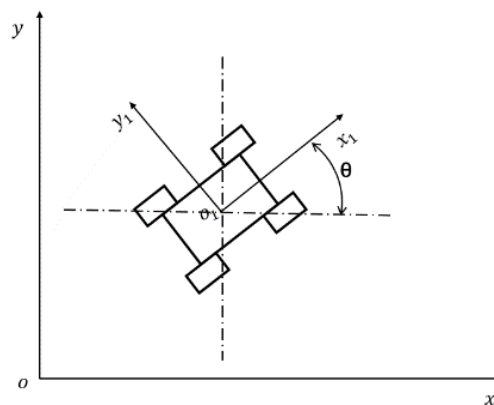


Figure 2: Relationship between Geodetic Local Coordinate System and Vehicle-mounted Coordinate System

#### 2.4. The Rectify Deviation Control of AGV

The AGV will continuously send its status information, such as its position and posture, to the scheduling system through UDP agreement. At the very beginning, the scheduling system will send the nearest point in the planned path to the AGV according to the current position of the AGV, and simultaneously send the two points in the subsequent path to the AGV, indicating the side attributes of the two adjacent points, such as the straight side, curve side, turning side, turning side when reversing into the pickup point, turning side when leaving the pickup point, etc.

The objective of AGV direction control is to reduce or eliminate the lateral position deviation and yaw Angle deviation between the actual position of AGV and the desired trajectory by automatically controlling the rotation Angle. With the lateral position deviation and yaw Angle deviation as the joint input parameters, PID classical control algorithm is adopted to obtain the total angle required for trajectory tracking. The general idea of the direction control algorithm is:

- (1) AGV receives waypoints sent by the scheduling system and stores them in a 3-D array.
- (2) The current position and posture information of the vehicle in real time through GPS sensor is obtained as the input of the direction control algorithm;
- (3) Pre-collimate along the current driving direction of AGV;
- (4) The total amount of lateral position deviation and yaw Angle deviation is calculated by the classical PID algorithm, and the steering control input is adjusted according to the speed to obtain the total steering angle required for trajectory tracking.

Among them, FIG. 3 shows the pre-collimated model of humanoid AGV path, displaying that any path can be fitted with straight lines and arcs. In the figure,  $xoy$  is the earth-based local coordinate system and  $x_1o_1y_1$  is the vehicle-mounted coordinate system. Then set the coordinates of the current position of AGV as  $(x_{n0}, y_{n0})$ , and the deflection Angle as  $\theta_{n0}$ . Pre-collimate a distance  $L$  along the front of the head-stock of the AGV (i.e., the positive direction of the  $x_1$  axis of the vehicle-mounted coordinate

system), and determine the position coordinates of the AGV at the initial preview point P as  $(X_p, Y_p)$ . Draw a straight line through P perpendicular to axis  $y_1$ , and its intersection point Q with the desired trajectory is the desired position  $(X_{pk}, Y_{pk})$ . The Angle between the tangent line of the trajectory through point Q and the  $x$  axis of the geodetic coordinate system is the yaw Angle  $\theta_{pk}$  of point Q which is the real pre-collimated point on the planned path. The position value of point Q can be obtained from the linear or circular equation that forms the predetermined trajectory.

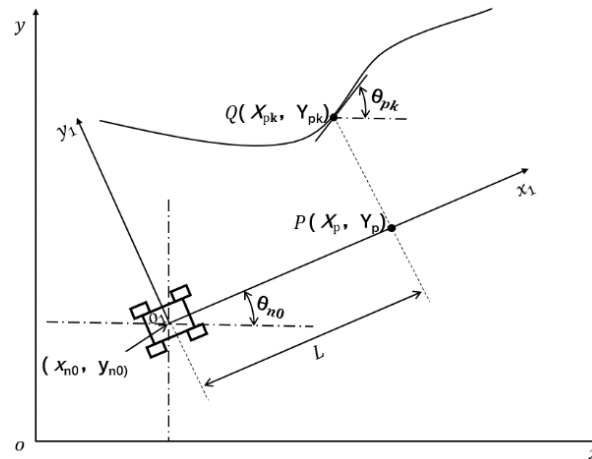


Figure 3: Model of Preview Path of AGV

Now, take an example of straight track tracking to illustrate the correction process of humanoid preview direction:

(1) Receive from the scheduling system the position and posture parameters of the two points (geodetic local coordinate system) on the planned trajectory. And the line formed by these two points is a straight.

(2) Ensure that the locations of the three points can be compared in the same coordinate system (equivalent to the local coordinate system at the origin rotated  $\theta$  Angle) by rotating the AGV current real-time point coordinates and the two points on the track line coordinates according to the formula (8) of  $\theta$  Angle. After the rotation, the values of  $x$ ,  $y$  of the three points are changed with the unchanged yaw Angles.

(3) Obtain the preliminary preview point by adding a fixed preview value  $L$  to the current point value  $X$  (direction of the head-stock) after the AGV is rotated.

(4) Obtain values of coordinates  $x_1$  and  $y_1$  of the preview point position on the trajectory of the planned line by substituting the values of the two points on the trajectory line after  $\theta$  Angle rotation into the equation  $y=kx+b$ , thus obtaining two constants  $k$  and  $b$  before inserting the  $x_1=x+L$  value of the preliminary preview point into the equation of the line so that the preview point  $y_1$  value can be easily obtained.

(5) The determination principle of yaw Angle of the preview point: if the preview point is behind the two points on the trajectory straight line, the yaw Angle of preview point is equal to that of the point nearer to AGV; If the preview point is in front of the two points on the trajectory line, the yaw Angle of the preview point is equal to that of the point farther from the AGV; If the preview point is midway between two points on the trajectory line, the yaw Angle of the preview point is equal to the mean of the difference between the yaw angles of the two input points, plus the yaw Angle value of the point closest to the AGV.

(6) Calculate the difference between the postures of previewing points and the postures of real-time AGV after rotation to obtain three temporary deviations,  $\Delta x$ ,  $\Delta y$  and  $\Delta\theta$ .

(7) Obtain the real-time lateral correction value  $y$  and yaw correction value  $\theta'$  by putting the values of  $\Delta y$  and  $\Delta\theta$  into the PID algorithm.

(8) Obtain the Angle for converting the lateral correction value into the direction correction by putting the lateral correction value into the formula.

(9) If the speed of AGV is positive and the direction is forward, the total direction correction value

of the output real-time tracking predetermined trajectory is  $\arctan(y' / \Delta x) + \theta'$ ; If the AGV speed is negative, it indicates that it is in reverse state, and the total direction correction value is  $\arctan(y' / \Delta x) - \theta'$ .

Arc tracking humanoid preview is similar to the above process. Firstly, it is necessary to set the Angle at which the AGV turns, which is generally no more than  $30^\circ$  due to the maximum Angle of the AGV hydraulic system, that is  $32.9^\circ$ , thus leaving some room for PID fine-tuning. Next, the AGV turning radius and the center point of the turning arc of the vehicle GPS receiver can be calculated according to the Ackerman Angle formula, and the arc equation can be listed, through which a fixed rotation Angle is previewed and the preview point is obtained. The Angle between the arc tangent through the preview point and the x axis is the yaw Angle of the preview point. In the actual calculation of the yaw Angle of the arc preview point, the obtained yaw Angle's starting point is  $0^\circ$  of the due east of the unit circle while the anticlockwise direction is positive because the range of yaw Angle given by IMU is  $0^\circ \leq \text{head} < 360^\circ$ . If the clockwise direction is positive and the due north direction is the  $0^\circ$  starting point, it needs to be transformed before it can be used.

### 3. Experimental Verification

The algorithm is deployed in AGV to carry out experiments in different environments, including the whole process of vehicle picking-up, conveying, putting-down and returning, which requires continuous operation. During the experiment, the transport vehicle can not be damaged, which requires the positioning accuracy and orientation accuracy of the AGV to reach  $\pm 25\text{mm}$  and  $\pm 0.1^\circ$  respectively in the process of operation.

In Figure 4, different experiment spots are shown. Through adjustment, AGV can complete the conveying task which takes a long time with suitability and reliability under different working conditions, indirectly verifying the accuracy and robustness of our algorithm.



A. Test at night



B. Rain and snow scenario test



C. Transport model vehicle



D. Transport real vehicles

Figure 4: Experiment Results

### 4. Conclusion

In this essay, a PID trajectory tracking algorithm combining the lateral position with the yaw Angle is proposed, which is also implemented in the AGV control system, combining with RTK-GPS positioning information, thus the centimeter-level trajectory tracking control of AGV is realized. The algorithm has been through tests before being deployed in AGV so as to control AGV to fulfill the conveying task in different spots. The experiments have approved that the algorithm can run stably and

reliably for a long time which can also be applied to other mobile robots with precise positioning information.

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