ABSTRACT

This paper is based on a dual-wheel drive differential steering AGV. In order to solve the problem of AGV tracking, firstly, AGV is conducted with kinematically modeling; then the PID controller is designed with the ante deviation as input and left and right driving wheel speed difference as output; and finally, simulation verification is carried out in the MATLAB/Simulink environment. The simulation results show that the designed PID controller has good tracking performance in straight line and circular path and it has strong adaptability and high robustness.

INTRODUCTION

AGV (Automated Guided Vehicle), refers to a transport vehicle equipped with an automatic guidance device such as electromagnetic or optical and capable of traveling along a prescribed guide route and having safety protection and transfer functions, with a wide range of application in various industries at home and abroad AGV.

This paper is based on a kind of AGV which is driven by DC motor and has dual-wheel differential steering. It mainly consists of a magnetic navigation sensor, a control single-chip microcomputer and a DC motor. The angle with the tape is measured by the magnetic navigation sensor and the steering is achieved through the control of drive motor by the single-chip microcomputer.

With the development of automatic control theory, system theory and computer technology, PID is widely used in industrial process control of metallurgy, chemical industry, electric power and machinery with its good control effect and reliability. In this paper, incremental PID control algorithm is applied to the AGV tracking control, to explore the role of PID control strategy in the automation control through theoretical analysis and computer simulation.
DIFFERENTIAL AGV SYSTEM STRUCTURE

The research object of this paper is the four-wheeled AGV as shown in Fig. 1; two independent driving wheels are symmetrically arranged on the left and right sides of the vehicle body, respectively driven by two DC brushless motors, and AGV steering is realized through two differential speeds. Both the front and rear are respectively equipped with a caster, playing a supporting role without effect on the body movement. The front end of the vehicle body is equipped with a magnetic navigation sensor, of which the upper inspection point is used to measure the declination of the relative tape, playing a guiding role. The tape is fixed to the ground, which is the theoretical trajectory of AGV.

![Figure 1. AGV structure diagram.](image)

DIFFERENTIAL STEERING AGV KINEMATICS MODEL

Dual-wheel differential steering AGV kinematics diagram (only two driving wheels are shown in the figure) is shown in Figure 2. For the convenience of AGV kinematics modeling, the following assumptions and simplification is made. It is assumed that the wheels roll at low speed in a two-dimensional horizontal plane and the two driving wheels are kept on the same axis. The center of gravity C of the AGV is located in the middle of the two driving wheels.

In Figure 2, XOY is geodetic coordinate system; O₁ and O₂ are left and right drive wheel center respectively; the wheel distance O₁O₂ is L; C is the center of O₁O₂; V_L, V_R and V_C are the velocities of left and right drive wheel center O₁, O₂ and AGV centroid C, respectively.
Take AGV centroid C as a reference point, then the AGV pose can be described by a vector $P = (X \ Y \ \theta)^T$. The AGV kinematics model is:

$$
\begin{bmatrix}
X \\
Y \\
\theta
\end{bmatrix}
= \begin{bmatrix}
\cos\theta & 0 & \frac{V_L + V_R}{2} \\
\sin\theta & 0 & \frac{V_L - V_R}{L} \\
0 & 1 & 0
\end{bmatrix}
\begin{bmatrix}
X_{(n+1)} \\
Y_{(n+1)} \\
\theta_{(n+1)}
\end{bmatrix}
$$

(1)

The pose $P_t$ of AGV at any moment $t$ is:

$$
P_t = \begin{bmatrix}
X_t \\
Y_t \\
\theta_t
\end{bmatrix} = P_0 + T \begin{bmatrix}
\int_0^t \frac{V_L + V_R}{2} \cos\theta dt \\
\int_0^t \frac{V_L + V_R}{2} \sin\theta dt \\
\int_0^t \frac{V_L - V_R}{L} dt
\end{bmatrix}
$$

(2)

Where, $P_0 = (X_0 \ Y_0 \ \theta_0)^T$, is the initial pose of AGV, at $t = 0$.

The discretized incremental expression is:

$$
P_{(n+1)} = \begin{bmatrix}
X_{(n+1)} \\
Y_{(n+1)} \\
\theta_{(n+1)}
\end{bmatrix} = P_n + T \begin{bmatrix}
\cos\theta_n & 0 & \frac{V_L + V_R}{2} \\
\sin\theta_n & 0 & \frac{V_L - V_R}{L}
\end{bmatrix}
\begin{bmatrix}
Y_n \\
\theta_n
\end{bmatrix}
$$

(3)

Where, $P_n = (X_n \ Y_n \ \theta_n)^T$, is the pose of AGV at the nth test, and $T$ is the sampling period.

Rewrite the above equation as a vector:

$$
y_{(n+1)} = P_n + B_n u_n
$$

(4)

Where, $B_n = T \begin{bmatrix}
\cos\theta_n & 0 & \frac{V_L + V_R}{2} \\
\sin\theta_n & 0 & \frac{V_L - V_R}{L}
\end{bmatrix}$; $y_n = P_n = (X_n \ Y_n \ \theta_n)^T$ is the input of the system;

$$
u_n = \left(\frac{V_L + V_R}{2} \frac{V_L - V_R}{L}\right)
$$

is the output of the system. AGV expected trajectory is $P_{rn} = (X_{rn} \ Y_{rn} \ \theta_{rn})^T$, pose error is $P_{en} = P_{rn} - P_n$; then the AGV tracking problem can be seen as seeking control law $u_n = \left(\frac{V_L + V_R}{2} \frac{V_L - V_R}{L}\right)$, which makes $P_{e(n+1)} \rightarrow P_{en}$. 

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PID CONTROL

The PID controller consists of a proportional link (P), an integral link (I) and a differential link (D). The basic PID control law can be described as:

\[ u(t) = K_P e(t) + \frac{1}{T_I} \int_0^t e(\tau) \, d\tau + T_D \frac{de(t)}{dt} \]  \hspace{1cm} (5)

(1) Proportional link (P): The signal deviation \( e(t) \) of the control system is proportionally reflected. Once the deviation is generated, the controller immediately controls to reduce the deviation.

(2) Integral link (I): Mainly used to eliminate static error and improve the system no difference. The role of integral depends on the integral time constant \( T_I \). The greater the integral time \( T_I \) constant, the weaker the integral effect is, vice versa.

(3) Differential link (D): It reflects the change trend (rate of change) of the deviation signal and introduces an effective early correction signal into the system before the deviation signal becomes too large, thus accelerating the system’s movement speed and reducing the adjustment time.

Discretization of Equation 5 gives the position equation of the PID controller. Replaced \( e(t) \) by the value of the sampling point \( e_n \):

\[ u_n = K_P [e_n + \frac{1}{T_I} \sum_{j=0}^n e_j + T_D (e_n - e_{n-1})] \]  \hspace{1cm} (6)

Where:
- \( K_P \) - Proportional amplification factor
- \( T_I \) - Integral time constant
- \( T_D \) - Differential time constant
- \( e_n \) - Angular deviation of AGV relative to tape at sample time \( n \)
- \( u_n \) - Control output

The above is the position PID control algorithm and the disadvantage is: due to the use of full output, each output is related to paste data \( e_n \) which should be accumulated during calculation. The amount of control output \( u_n \) by the computer corresponds to the actual position deviation of the actuator. If the position sensor fails, \( u_n \) can change drastically, causing a drastic change in the position of the implementing agency, which is not allowed in production and may even result in major accidents. To avoid this situation, the incremental PID control algorithm should be adopted.

Incremental formula regulator output is the amount of control increments of each step:

\[ u_{(n-1)} = K_P [e_{(n-1)} + \frac{1}{T_I} \sum_{j=0}^{n-1} e_j + T_D (e_{(n-1)} - e_{(n-2)})] \]  \hspace{1cm} (7)

The increments of the \( n \)th and (n-1)th sampling outputs are:

\[ \Delta u_n = u_n - u_{(n-1)} = K_P \left[ (e_n - e_{(n-1)}) + \frac{1}{T_I} e_n + T_D (\Delta e_n - \Delta e_{(n-1)}) \right] \]

\[ = K_P \left[ (e_n - e_{(n-1)}) + \frac{1}{T_I} e_n + T_D (e_n - 2e_{(n-1)} + e_{(n-2)}) \right] \]  \hspace{1cm} (8)

This is an incremental PID control expression. Incremental PID algorithm has the following advantages: (1) calculation does not require accumulation. The determination of control increment \( \Delta u_n \) is only related to the sample values of the last 3 times, and it is easy to get better control effect through weighted processing. (2) The computer outputs only the control increment at a time, which corresponds to the change of the position of the actuator. Therefore, when the machine fails, the influence range is small and the production process will not be seriously affected. (3) The impact during the manual-automatic switching is small. The control switch from manual to automatic can be carried out freely.

In the context of this paper, AGV is a dual-wheel differential drive, that is, the steering of the AGV body is realized by controlling the speed of the left and right driving wheels. In
the AGV tracking process, actually the AGV body position relative to the tape needs to be controlled. In this paper, based on the magnetic navigation sensor, AGV continues collecting information on the path ahead and calculate the position deviation of the body relative to the tape as PID control input deviation and then it calculates the speed increment of the left and right wheels in each sampling period with the incremental PID control algorithm. The trajectory error is constantly updated to achieve the purpose of AGV tracking.

The control process is shown in Figure 3.

Where, e(n) is the position deviation of AGV body relative to the tape in the nth control cycle; VL(n) and VR(n) are the speeds of the left and right driving wheels of the AGV body in the nth control cycle; Δu(n) is the incremental output of incremental PID control algorithm in the nth control cycle.

**COMPUTER SIMULATION**

In this paper, the mathematical model of the research object is built using MATLAB/Simulink platform. The distance between left and right drive wheels \( L = 450mm \); the average speed of AGV \( V_c = 0.6m/s \). According to the actual working conditions, the working path of AGV is composed of a straight line and a circular arc. Therefore, this paper simulates the following effect of AGV in both straight line and circular arc path.

Through the system identification, the mathematical model of the transfer function of the controllable object can be obtained: \( G(s) = \frac{\omega^2}{s^2 + 2\zeta \omega s + \omega^2} \), where \( \omega = 3 \), \( \zeta = 3 \). The sampling time is 1ms.

The pros and cons of PID control depends on the setting of the PID controller parameters. PID controller parameter setting is the core content of PID control system design. According to to the characteristics of the controlled process, it determines PID controller proportional amplification factor \( K_p \), integral time constant \( T_i \) and differential time constant \( T_D \).
In the practical application, PID controller parameter setting adopts engineering setting method, which is characterized by: the controller parameter is set according to the engineering experience equation through testing and the obtained PID controller parameters need to be carried out with final adjustment and improvement in the actual operation, without prior knowledge of the process of the mathematical model. The filed setting is conducted directly in the process control system, which is simple with easy calculation. In this paper, one of engineering methods—Z-N critical ratio method is adopted for the setting of proportion amplification factor $K_p$, integral time constant $T_i$ and differential time constant $T_D$.

(1) Straight line path

The expected path is $y = 0$; the initial pose and attitude matrix of AGV is $(0 \ 200 \ \pi/6)^T$; time unit: s; distance unit: mm. PID control path following situation simulation results are shown in Figure 4, where, the dotted line is the expected path and the solid line is the actual path.

![Figure 4. PID control simulation results under the straight line path.](image)

(2) Circulation arc path

The expected path is $x^2 + y^2 = 100^2$; the initial pose and attitude matrix of AGV is $(0 \ 80 \ \pi/6)^T$. PID control path following situation simulation results are shown in Figure 5, where, the dotted line is the expected path and the solid line is the actual path.

![Figure 5. PID control simulation results under arc path.](image)
It can be seen from the simulation results of straight line trajectories and circular arc trajectories: PID control overshoot is small or is even eliminated with short adjustment time and good dynamic characteristics. This control method can effectively correct AGV deviation and track the path.

CONCLUSION

This paper studies a kind of dual-wheel differential drive AGV. Based on the analysis of the AGV kinematics model, a PID controller suitable for the system is designed and applied to the tracking control of AGV mobile robot. It achieved good control effect through parameter setting in the simulation verification by the way of MATLAB/Simulink.

The simulation results show that the designed PID controller can make the AGV system track good under the straight line path and the circular arc path with strong adaptability and high robustness. In the conventional production, the method used in this study has a greater reference value.

ACKNOWLEDGEMENT

The article was supported by the project of Shandong Provincial Key Project (2017CXGC0903), Shandong Provincial Key Project (2017CXGC0810), Shandong Provincial Key Project (2017CXGC0215).

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