Research on control algorithm of a automatic driving robot based on improved model predictive control

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Abstract. The automatic driving robot can replace the driver in the traditional test and ADAS test; Model Predictive Control (MPC) is used in the horizontal and vertical control process of high-speed driving. According to the uncertainties and complex constraints of automatic driving horizontal and vertical control, the adaptive improvement of MPC is proposed, which can better adapt to the characteristics of self-driving vehicles, sensors and tyres. This paper proposes a multi-layer and multi-time automatic driving control strategy based on improved MPC. Visual studio is used to write the upper computer software of the automatic driving robot, which realizes good human-computer interaction. The automatic driving robot is verified in real vehicle test. The experimental results show that the transverse and longitudinal control strategy of the improved model predictive control is stable, and the automatic driving robot can realize the high precision and high dynamic control of vehicle steering, pedal and shift.

1. Introduction

Automatic driving robot has the advantages of high precision control, good repeatability, strong fatigue durability and so on. The automatic driving robot can be used for vehicle durability test and ADAS test such as AEB and FCW; it can also be used in operation scenarios such as smart mine and wharf. The automatic driving robot based on the improved model predictive control has the advantages of simple scheme, many control mechanisms, strong durability, fast response and many vehicle tests. The automatic driving robot includes steering robot, pedal robot, gear robot and human-computer interaction system suitable for various tests; it has the characteristics of compact structure, easy maintenance, simple control, easy installation and calibration, and suitable for a variety of vehicles. In this paper, the horizontal and vertical joint control scheme and control strategy are adopted. By selecting different switching modes, different vehicle tests are completed. The control effect is good, the response speed is fast and the tracking effect is good [1, 2].

The control system of automatic driving robot includes perception unit, decision unit, control unit, execution unit and application unit. The decision-making unit is the upper computer and human-computer interaction software; the control unit includes the controller; the perception unit includes lidar, vision sensor and integrated positioning inertial navigation; the execution unit includes steering robot, pedal accelerator robot, shift robot, emergency stop and teaching device. Figure 1 is the system planning block diagram of autonomous robot.
2. Methods

In order to meet the control requirements of automatic driving robot, a distributed control system is adopted. The software system is divided into three layers: decision-making layer, control layer and execution layer. The decision-making layer mainly makes decisions according to the environment and requirements. The control layer mainly controls the transverse and longitudinal direction of the automatic driving robot. The execution layer mainly controls the vehicle steering and acceleration and deceleration by the driving motor of the automatic driving robot Communicate with each other and share information [3, 4].

2.1. Control Strategy

The control strategy is mainly to control the speed and direction of the vehicle, that is, the lateral control and longitudinal control of the automatic driving robot. In the road test, the vehicle direction control is mainly considered, which is a typical preview control behavior. It needs to find the preview point in the current road environment through the driving robot, and then control the vehicle according to the preview point.

In the lateral control, the "preview tracking" control strategy is used in the process of testing the vehicle. In order to achieve the control effect of the autonomous driving robot, the control parameters of the lateral and longitudinal joint control are optimized, and the control system of the autonomous driving robot is constructed. The horizontal and vertical joint control architecture is divided into decision-making layer, control layer and execution layer As shown in Figure 2, the horizontal and vertical control strategy of automatic driving robot is presented.

According to the vehicle, the coordinate system is established and the desired trajectory, desired steering speed, desired speed and desired acceleration are given regularly; the current speed, acceleration and deceleration are calculated through the feedback of vehicle speed and absolute encoder of brake or throttle robot motor, and the brake and throttle robots are controlled in real time through PID adjustment. The desired steering angle and speed are calculated by the lateral controller,
and the steering wheel control quantity is calculated by adjusting the absolute encoder of the steering robot motor and the steering wheel angle sensor.

2.2. Trajectory optimization based on kinematics and dynamics

Automatic driving robot adds vehicle kinematics and dynamics to path planning, which makes it easier to control vehicle tracking path and the effect of path tracking better. The process of vehicle motion on the ground is very complex. This process is described by establishing a simplified two wheel two degree of freedom steering model, as shown in the figure below.

![Figure 3. Control system scheme of the Automatic driving robot.](image)

![Figure 4. Schematic diagram of vehicle position prediction.](image)

According to the two degree of freedom steering model, the gain of vehicle steady-state yaw rate is as follows:

$$\frac{\omega_y}{\delta} = \frac{u}{L} \frac{1}{1 + Ku^2}$$

(1)

Then the steady-state yaw rate is:

$$\omega_y = \frac{u\delta}{L(1 + Ku^2)}$$

(2)

In the above formula, $K = \frac{m}{L^2} \left( \frac{a}{k_1} - \frac{b}{k_2} \right)$, m is the mass of the target vehicle, a is the distance between the mass center of the target vehicle and the front axle, b is the distance between the mass center of the target vehicle and the rear axle, l is the wheelbase of the target vehicle, that is, the sum of a and b, $k_1$ is the lateral stiffness of the front wheel, $k_2$ is the lateral stiffness of the rear wheel, u is the velocity component of the target vehicle along the x-axis in the body coordinate system, and $\delta$ is the front wheel angle.

The turning radius $r$ in steady state is:

$$r = \frac{u}{\omega_y} = \frac{L(1 + Ku^2)}{\delta}$$

(3)

Suppose that the current position of the target vehicle is $(X_0, Y_0)$, the heading angle is $\theta_0$, after the time $t$, the position of the vehicle is $(X_t, Y_t)$, the heading angle is $\theta_t$, then the change of the vehicle heading angle is

$$\theta = \omega_y \cdot t$$

(4)

As shown in the figure below, the increment $\Delta X$ and $\Delta Y$ of the position of the vehicle on the x-axis and y-axis at time $t$ in the future, then
\[ \Delta x = R \sin \theta = \frac{L(1 + Ku^2)}{\delta} \sin \left( \frac{u \delta}{L(1 + Ku^2)} t \right) \]
\[ \Delta y = R(1 - \cos \theta) = \frac{L(1 + Ku^2)}{\delta} \left( 1 - \cos \left( \frac{u \delta}{L(1 + Ku^2)} t \right) \right) \]

Then after t time, the position of the car:
\[ \begin{cases} X_t = X_0 + \Delta x \\ Y_t = Y_0 + \Delta y \end{cases} \] (6)

The heading angle is:
\[ \theta_t = \theta_0 + \theta \] (7)

2.3. Improved model predictive control

The lateral control adopts model predictive control (MPC). In each sampling period, the current control sequence is obtained by solving a finite time-domain open-loop optimal control problem. The current state of the system is regarded as the initial state of the optimal control problem, and only the first control action is executed in the optimal control sequence, which is the biggest difference between the control method and the control method which uses the priority to solve the control law [5].

The model predictive control system consists of predictive model, reference trajectory, rolling optimization and online correction, as shown in the figure below. The input of reference trajectory is \( s(k) \) and \( y(k) \), and the output is \( y_d(k + 1) \); the input and output of predictive model are \( u(k) \) and \( Y_M(k + 1) \); the input and output of controlled object are \( u(k) \) and \( y(k) \), respectively.

![Figure 5. Block diagram of model predictive control system.](image)

The principle of model predictive control is shown in the figure below. The k-axis is the current state, the left is the past state, and the right is the future state. Model predictive control (MPC) is a kind of optimal control problem which aims to decompose a longer time span or even infinite time into several shorter time span or finite time span optimal control problems, and still pursues the optimal solution to a certain extent.

![Figure 6. Principle of model predictive control.](image)

![Figure 7. Improved model predictive control.](image)
In the process of MPC rolling optimization, some model parameters are fixed, so it is difficult to find the disturbance in time; and the traditional MPC has limited sampling period, so it is difficult to deal with complex constraints. The prediction output is optimized based on the k-time plan, and the real-time control quantity is optimized based on the improved MPC and the k-time optimization results at the k + 1 time, so as to optimize the target and improve the accuracy of the results.

The step size of MPC initial prediction domain is $N_p$, the step size of prediction domain and control domain is shortened by $L_1$, and the current time is $k$. A single initial control interval includes $s_0$ minimum sampling intervals. According to the maximum fluctuation amplitude of uncontrollable input prediction value in the control interval, a single control interval includes $m$ minimum sampling intervals, which is $L_2$ shorter than $s_0$.

3. Experiment

3.1. Vehicle parameters

The real vehicle parameters are shown in Table 1

| Numble | Vehicle Parameters | Value               |
|--------|--------------------|---------------------|
| 1      | Car length, width, height | 4554*1855*1719mm   |
| 2      | Car weight (m)      | 1730kg              |
| 3      | The distance between the center of mass of the car and the front axle (a) | 1232mm |
| 4      | The distance between the car and the rear axle (b) | 1468mm |
| 5      | Car wheelbase (L)   | 2700mm              |
| 6      | Maximum power       | 124kW               |
| 7      | Front tire cornering stiffness (k1) | 66900  |
| 8      | Rear tire cornering stiffness (k2) | 62700  |

3.2. Experiment

3.2.1. Driving robots. The three-dimensional model of the steering robot is shown in the figure below. The steering robot and pedal robot of the automatic driving robot are installed in the car, as shown in the figure below.

Figure 8. Three dimensional model of steering robot.

Figure 9. Driving Robots.
3.2.2. Steering test. The steering angle and lateral acceleration data of the vehicle collected in the moose test are shown in the figure below.

![Figure 10. Lateral acceleration.](image)

![Figure 11. The rotating angle from the steering wheel.](image)

4. Conclusion
In this paper, the transverse and longitudinal control strategy of autonomous robot is established firstly. Through the trajectory optimization of dynamics and kinematics of autonomous robot, the modified strategy based on model predictive control is proposed. Finally, the autopilot robot is verified in the real vehicle test. The experimental results show that the autopilot robot has stable transverse and longitudinal control, good control of vehicle steering, pedal and shift, and good control of autopilot robot.

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