Research on Unmanned Static Trajectory

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Abstract. With the development of science and technology, the intelligence of society is getting higher and higher. The development of safe and reliable intelligent driving has become one of the important topics in today's era. As a high-tech complex integrating environmental awareness, planning decision-making, control execution and information interaction, driverless cars are increasingly becoming the needs of the times. [1] How to accurately extract effective information to provide safe and reliable control instructions for the next decision-making of vehicles in complex multi-source and heterogeneous environment is the technical basis of intelligent driving.

In this paper, a certain amount of research has been done on lane change trajectory planning in different environments. In the aspect of static driving environment, a lane-changing trajectory planning method based on the fifth-order Bessel curve is planned. The physical problems are transformed into optimization problems of coordinate points of Bessel curve expression by planning the left and right boundaries of feasible region through lane-changing trajectory. [2] In the aspect of dynamic driving, based on the model predictive control theory, a lane-changing trajectory optimization method for multi-lane and multi-surrounding vehicles is proposed.

1. Introduction

1.1 research background

As a high-tech industry in the national manufacturing industry, the technical level of automobile industry can influence a country's comprehensive strength to some extent. After years of development, the global automobile industry has entered a relatively mature and stable stage. [3] However, with the continuous progress of science and technology, AI technology has gradually penetrated into various fields, and driverless technology has become an important research branch in the field of automobile industry.

Unmanned vehicle can become a mobile robot, and its realization and technical research mainly include three key contents: 1. The vehicle's perception of surrounding environment and the recognition and processing of surrounding information. 2. The car analyzes and integrates the collected information, makes the next behavior decision, and completes the trajectory planning of the target; [4] 3. The response and execution of automobile system to external instructions.

In the complex driving environment with multiple sources and heterogeneity, it is of great research significance for realizing the industrialization of intelligent driving technology to work out safe and
reliable driving decision-making schemes and plan smooth and feasible driving paths in different environments.

Trajectory planning, as the key content of intelligent driving, has attracted more and more attention from researchers at home and abroad. In the existing research, there are many path planning methods for local paths. Among them, the reference frequency is high mainly as follows: 1. Trajectory planning method based on lane change. 2. Trajectory planning method based on positive and negative trapezoidal lateral acceleration. 3. Trajectory planning method based on polynomial. 4. Trajectory planning method based on artificial potential field and Bessel curve.

2. Track change planning based on static environment

2.1 trajectory planning based on the principle of positive and negative trapezoidal lateral acceleration

Vehicle operation is a dynamic model, and lane changing and overtaking operations are the comprehensive behavior process that drivers adjust and complete according to their own driving characteristics, considering the surrounding driving environment such as the speed and spacing of surrounding vehicles. In order to realize the automatic lane change of unmanned vehicles, a feasible lane change trajectory should be planned according to the vehicle form and road information, and the lane change control law should be designed to track the vehicle. [5] Therefore, the planning of lane change trajectory has become a prerequisite for the realization of lane change for unmanned vehicles.

At present, there are various methods for lane change trajectory planning. Among them, the planning and design idea of lane-changing trajectory based on polynomial is to construct curve clusters of lane-changing trajectory with quintic polynomials in X direction and Y direction, and plan lane-changing trajectory according to the initial state and target state of the vehicle, so that the vehicle can reach the adjacent lane at the specified time. This method can ensure smooth lane change within the specified lane change time, and can strictly reach the desired position in the longitudinal and lateral directions, and the curvature of the trajectory curve can reach the expected value of zero at the starting point and the end point. However, this method has the limitation that the time and end point of lane change must be known in advance, and the determination of each parameter in the polynomial needs sufficient constraints, so it has poor maneuverability and adaptability to the change of longitudinal vehicle speed and the end point of the actual lane change process.

In view of the fact that most of the existing studies only focus on lane change trajectory planning at constant vehicle speed, and considering the actual working conditions of lane change operation at different vehicle speeds, a lane change trajectory planning method is proposed based on the positive and negative trapezoidal lateral acceleration method, which takes into account both safety and comfort and can adapt to different vehicle speeds. [6] The optimal solution of lateral acceleration and lateral acceleration rate is obtained by optimizing the multi-objective function, which replaces the manual method and provides a new solution for the optimal planning of lane change trajectory based on this method.

2.2 positive and negative trapezoidal lateral acceleration method

The method of positive and negative trapezoidal lateral acceleration is based on the lateral acceleration of lane-changing vehicles. It is assumed that the shape of the lateral acceleration of vehicles is composed of two positive and negative trapezoids with the same size during lane-changing operation on a straight road, and the lane-changing trajectory curve is obtained by integrating the lateral acceleration twice. The mathematical expressions corresponding to the desired lateral acceleration and lateral acceleration rate are shown as follows:
Ay is the lateral acceleration, aymax is the maximum lateral acceleration, Jy is the maximum lateral acceleration rate, and Jmax is the maximum lateral acceleration rate.

It can be obtained from this:

\[
a_y = \begin{cases}
  J_{y\text{max}} t & 0 \leq t \leq t_1 \\
  a_{y\text{max}} & t_1 \leq t \leq t_2 \\
  a_{y\text{max}} - J_{y\text{max}}(t-t_1) & t_2 \leq t \leq t_3 \\
  -a_{y\text{max}} & t_3 \leq t \leq t_4 \\
  -a_{y\text{max}} + J_{y\text{max}}(t-t_1) & t_4 \leq t \leq t_5 
\end{cases}
\]

\[
J_y = \begin{cases}
  J_{y\text{max}} & 0 \leq t \leq t_1 \\
  0 & t_1 \leq t \leq t_2 \\
  -J_{y\text{max}} & t_2 \leq t \leq t_3 \\
  0 & t_3 \leq t \leq t_4 \\
  J_{y\text{max}} & t_4 \leq t \leq t_5 
\end{cases}
\]

\[\begin{align*}
t_1 &= a_{y\text{max}} / J_{y\text{max}} \\
t_2 &= \frac{a_{y\text{max}}}{2J_{y\text{max}}} + \sqrt{\left(\frac{a_{y\text{max}}}{J_{y\text{max}}}\right)^2 + 4d_w / a_{y\text{max}}} \\
t_3 &= 2t_1 + t_2 \\
t_4 &= t_1 + 2t_2 \\
t_5 &= 2t_1 + 2t_2
\end{align*}\]

In the formula, dw is equivalent to the lateral displacement during lane change. This paper assumes the lane width and takes the standard width of 3.5 meters.

![Figure 1: Schematic diagram of positive and negative trapezoidal lateral acceleration](image)

From the above, it can be deduced that both the lateral acceleration value and the lateral acceleration rate can be expressed by an expression composed of two variables, t1 and t2, namely:
The whole lane change time can be expressed as:

\[ t_{1c} = t_5 = 2t_1 + 2t_2 \]

At the same time, in the process of lane change, we must first ensure driving safety, and the lateral acceleration and lateral acceleration rate should not exceed a certain range: the lateral acceleration value is 0.1m/s²-0.2m/s²; The range of lateral acceleration rate is 0-1m/s².

Therefore, the trajectory solidification problem can be transformed into a mathematical nonlinear programming problem with the shortest whole lane change time for the same lane change lateral moving distance under the constraint of maximum lateral acceleration and lateral acceleration rate.

2.3 the establishment and optimization of objective function

The indexes to measure the advantages and disadvantages of lane change process are lateral acceleration, yaw angle amplitude, lane change time and lane change distance. The multi-objective function of lane change process is established by comprehensively considering the above-mentioned lane change indexes.

\[ \min F = \omega_t a_{y_{\text{max}}} + \omega_r J_{y_{\text{max}}} + \omega_v a_{y_{\text{max}}} + \omega_{t_1} t_1 + \omega_{x_{\text{lat}}} x_{\text{lat}} \]

In the formula, \( a_y \) and \( \omega_r \) represent lateral acceleration and yaw rate respectively; \( v_x \) indicates the vehicle speed; \( K \) represents the vehicle driving stability factor; \( L \) is the wheelbase of the vehicle; \( M \) is the vehicle servicing mass; \( A \) and \( b \) are the distance between the center of mass of the vehicle and the front and rear axles respectively; \( c_f \) and \( c_r \) are the cornering stiffness of the front and rear tires respectively.

According to formula 3-6, the expression of maximum yaw angle amplitude can be obtained:

\[ \omega_{r_{\text{max}}} = \frac{d_w}{t_2^2 + t_1 t_2} / v_x \]

The decibel of lane change time and lane change distance can be expressed as:

\[ t_{1c} = 2t_1 + 2t_2 \]

\[ x_{\text{lat}} = v_x (2t_1 + 2t_2) \]

By 3-6, 3-11, 3-12 and 3-13, the objective function can be transformed into:
In the formula, \( a_{\gamma_{\text{min}}} \) is the left boundary of \( a_{\gamma} \) and \( 0.1 \text{ m} / \text{s}^2 \); \( a_{\gamma_{\text{max}}} \) is the right boundary of \( a_{\gamma} \), \( 0.2 \text{g m} / \text{s}^2 \). In addition, the optimization variables \( t_1 \) and \( t_2 \) need to satisfy the lower limit condition of not less than 0 at the same time.

Through optimization, the relationship between strain track time and maximum lateral acceleration index under different weighting coefficients can be obtained.

3. Summary and prospect

3.1 Summary

In this paper, the key technologies for unmanned vehicles in static environment are studied, and a relatively perfect implementation scheme for unmanned vehicles in static environment is designed from the core technology of trajectory planning. The main work of this paper is as follows: The trajectory planning of free lane change in static environment is studied, and the lane change trajectory which can adapt to different driving speeds is planned. The function optimization problem is transformed into the optimization solution problem of Bessel curve expression and coordinate points, and the optimal lane change trajectory satisfying the conditions is planned.

3.2 Outlook

From the aspect of driving behavior decision-making, the follow-up research work should rely on big data resources, build a database that can truly reflect driving environment information, and explore more accurate driving behavior decision-making methods.

From the aspect of trajectory planning, the follow-up research work will be carried out from the formal working conditions with more complex driving environment and more diverse road conditions, and a more universal trajectory planning method will be studied for emergencies under different extreme conditions.[7]

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