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A study of Vehicle Lane-changing Trajectory Based on Polynthics

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Abstract

The efficient lane-changing of vehicles can improve the driving efficiency of vehicles, improve the efficiency of road traffic and reduce traffic pollution. Based on the polynomial lane-changing trajectory model, considering the vehicle dynamics and motion constraints, the vehicle change track model is optimized, and the results show that the optimized model can follow the trajectory change vehicle very well.

Keywords

Trajectory planning, polynomial model, CarSim software.

1. Introduction

The level of production and living standards of our people have improved greatly in recent years, but this improvement and development has also resulted in many other problems, traffic congestion is one of them. In recent years, the development of big data, deep learning and artificial intelligence technology has made it possible to realize self-driving vehicles, and the development and application of self-driving technology will provide us with a new way to solve the problem of traffic congestion. The implementation of self-driving technology needs to solve many problems, one of which is the change of lane technology of self-driving vehicles.

Regarding the study of the vehicle's lane-changing model, Yang Zhigang's track-changing trajectory model based on the sine function, combined with the advantages of the iso-speed offset trajectory model, the lane-changing trajectory is optimized to obtain a smoother trajectory fitting curve[1]. A segmented approximation method with a double arc of the secondary uniform B-sample curve is proposed. The constructed double arcs are connected together to form an approximate curve of the secondary uniform B-pattern curve[2]. Based on the swing curve,NanChunli has established three parabolic models of the vehicle's travel trajectory, which further fits the changes in the vehicle's trajectory[3]. Li Wei studied the lanechange trajectory on the basis of the B-sample theory and obtained a model of a free-change of vehicles on the highway. Using a 7-way multi-directional track model[4]. Wang Chang matched the lateral displacement of the lane-changing in the process with the time course of the corresponding vehicle change, and predicted the time of the vehicle's cross-line in the vehicle lane-changing track[5].Polynthic track model has high reliability and low computation, and is also suitable for track change planning in complex traffic conditions, and there are no defects such as curvature mutation and indesequity, while the acceleration change model is more flexible[6,7]. Therefore, this paper considers the combination of polynthic track model and cosine function track model to optimize the vehicle lane-changing.

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2. Analysis of vehicle lane-changing

Vehicle lane-changings are designed to allow the vehicle to drive faster, or to avoid traffic accidents, from the original lane to the target lane, ultimately reducing travel time. In general, the higher the frequency of vehicle lane-changings on a road section, the less road capacity, the less efficient the traffic operation, and the greater the likelihood of accidents.

Before using the I-80 dataset to study lane-changings, vehicle lane-changing data should be filtered to make the lane-changing data simulated below more accurate[8]. The basic processing of lane-changing data begins with the conversion of the length unit from feet to m,followed by the following considerations:

(1) Filter out data about cars of vehicle type. The focus of this vehicle change study is not on the change of lanes for motorcycles and large trucks, so the first step is to filter out the data about the car, i.e. v-Class 2.

(2) Filter out vehicle data with lane-changing behavior . Vehicle data for vehicle lane-changing should be selected for study, and vehicles without lane-changing behavior are not covered by thisstudy, i.e. count(Lane_ID).

(3) filtersoutthe total number of frames that appear in the vehicle in the data set to exceed 173(the total length of the detection area is 503m, the maximum speed of the vehicle is 104.57km/h,and the maximum speed ofthe vehicle passesthrough this area requires 17.3s, the number of frames of the vehicle can be detected at 173), i.e. Total_Frames

(4) Filter out the track data of the vehicle as soon as it enters the detection area. This study of vehicle change is around the traffic vehicle impact under the premise, so consider screening out the vehicle change data with the impact of the front car, but also because the vehicle just entered the detection area, whether the vehicle has a rear car to follow this status data can not be detected, so the vehicle with the impact of the rear vehicle change is not considered as a screening consideration.

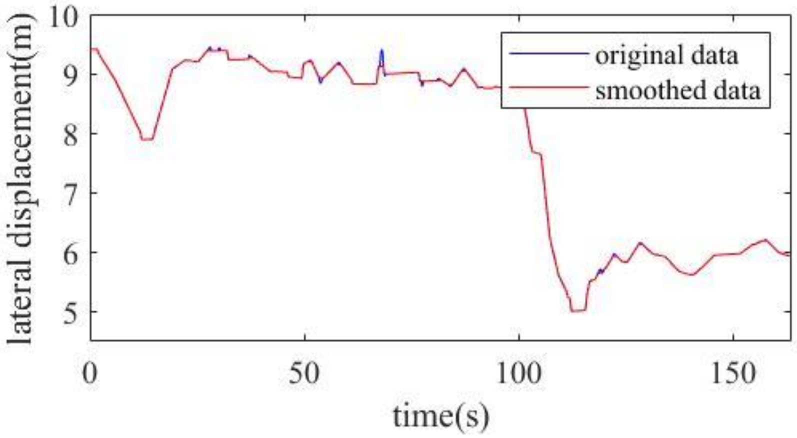
After a preliminary screening of the lane-changing data, combined with the reality detection area of the I-80 data set, lane 1 is an HOV lane with less vehicle lane-changing behavior, lane 6 is an inbound and outbound lane, lane 5 is more affected by lane 6 traffic, lane 3 is in the middle of lane 2, lane 3, and lane 4, so consider the lane 3 as the initial lane of the vehicle. After filtering it, you Vehicle_ID set of track data with a total of 1637 tracks with a total of 2618.

The Vehicle_ID data with a value of 2618 is processed, and the track data is smoothed by the symmetrical exponential moving average method.

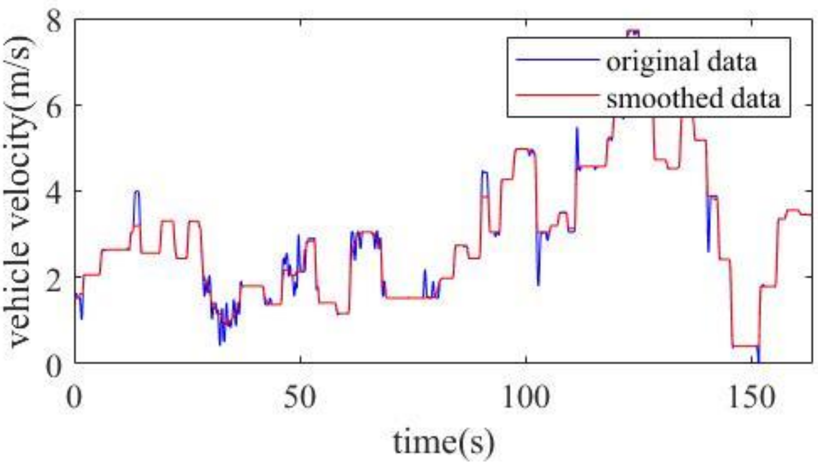
$$\begin{cases} \dot{x}_m(k) = \sum\limits_{n=k-D}^{k+D} x_m(k) e^{-|n-k|/\Delta} \Big/ \sum\limits_{n=k-D}^{k+D} e^{-|n-k|/\Delta} \\ D = \max\{3\Delta, k-1, N_m - k\} \end{cases} \tag{1}$$

In the formula: m is the vehicle; $\dot{x}_m(k)$ is the lane-changing vehicle to fit the value at the moment, $x_m(k)$ is the lane-changing vehicle for original measurement value at the moment k; D is the smooth window that considers the boundary that is Δ , $\Delta = T/d_t = 10T$; N_m is the frames in the detection section of the vehicle m .

The lateral displacement and vehicle speed smoothing are calculated as figure 1.



(a) The horizontal displacement of the vehicle



(b) Vehicle speed

Figure.1 Smoothing of vehicle track data

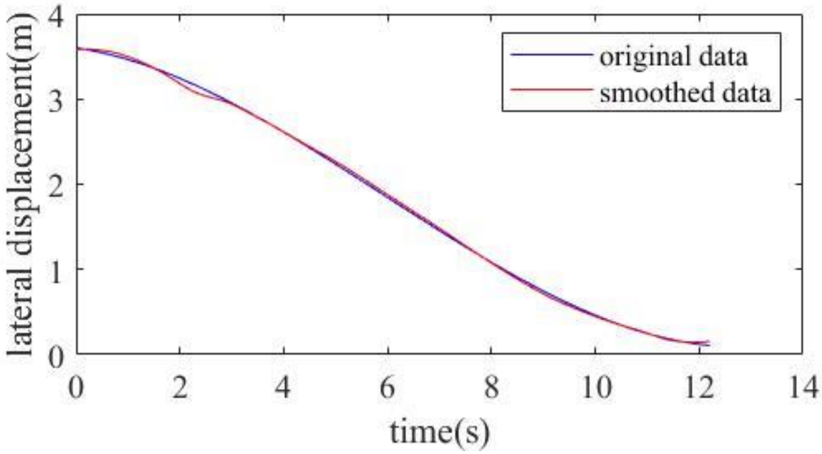
In order to obtain the complete single lane-changing behavior and avoid filtering to incomplete monitoring of incomplete lane-changing and lane-changing data, the following constraints are used as the basis for selecting the data for the complete lane-changing of vehicle:

(1) Determination of the starting point of the lane-changing: from that point on, the transverse coordinates remain monotonously increasing or decreasing, the duration is at least 15 frames, and each frame change is greater than 0.1ft, that is 0.03048m

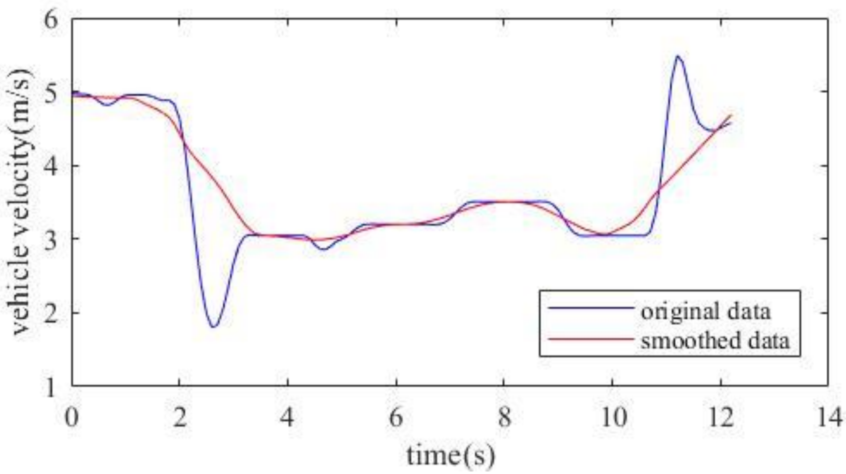
(2) Determination of the end point of the lane-changing: within 12 seconds from the starting point of the lane-changing, the monotony of the lane-changingr vehicle at a certain point is consistent with the starting point of the lane-changing, but the change per frame is less than 0.03048m, and the change in each frame in the next 5 frames is less than 0.03048 m, the point that meets this condition and is closest to the starting point of the lane-changing is the end point of the lane-changing;

(3) Limitations of transverse displacement: Considering a single lane-changing, the horizontal coordinate change from the beginning of the lane-changing to the end of the lane-changing is greater than 3m.

The resulting vehicle lane-changing data is shown in the figure 2:



(a) Vehicle lane-changing trajectory



(b) Vehicle lane-changing speed

Figure.2 Vehicle lane-changing track and lane-changing speed

3. Establish vehicle lane changing model

Vehicle lane-changing model seven polynomial curve equations are:

$$\begin{cases} x(t)=\sum_{i=0}^{7} a_i t^i = a_7 t^7 + a_6 t^6 + a_5 t^5 + a_4 t^4 + a_3 t^3 + a_2 t^2 + a_1 t + a_0 \\ y(t)=\sum_{i=0}^{7} b_i t^i = b_7 t^7 + b_6 t^6 + b_5 t^5 + b_4 t^4 + b_3 t^3 + b_2 t^2 + b_1 t + b_0 \end{cases} \tag{2}$$

In the formula: $x(t)$, $y(t)$ is the horizontal and ordinates in the process of vehicle lane, respectively; t is the change lane time; a_i b_i is the parameters of can be calculated (i =1,2 ... 7). $y(t_0)$, $\dot{y}(t_0)$, $\ddot{y}(t_0)$, $\dddot{y}(t_0)$, $x(t_0)$, $\dot{x}(t_0)$, $\ddot{x}(t_0)$ is the initial status of the vehicle, respectively. $y(t_1)$, $\dot{y}(t_1)$, $\ddot{y}(t_1)$, $\dddot{y}(t_1)$, $x(t_1)$,, $\dot{x}(t_1)$, $\ddot{x}(t_1)$, $\dddot{x}(t_1)$ is the target status of the vehicle, respectively.

As can be known from the geometric relationship, the mathematical relationship between the four vertices *A, B, C, D* and the center of the rear axle of the vehicle results in the coordinates of the body vertebrae *A* as (x_A , y_A), the coordinates of the body vertebrae *B* as (x_B , y_B),the coordinates of the body vertebrae *C* as (x_C , y_C) and *the coordinates of the body vertex D* as (x_D , y_D). The trajectory of the body vertex to the center point of the vehicle is:

$$\begin{cases} x_A = x - \frac{w}{2}\sin\theta - \frac{l}{2}\cos\theta \\ y_A = y + \frac{w}{2}\cos\theta - \frac{l}{2}\cos\theta \\ x_B = x + \frac{w}{2}\sin\theta - \frac{l}{2}\cos\theta \\ y_B = y - \frac{w}{2}\cos\theta - \frac{l}{2}\cos\theta \\ x_C = x + \frac{w}{2}\sin\theta + \frac{l}{2}\cos\theta \\ y_C = y - \frac{w}{2}\cos\theta + \frac{l}{2}\cos\theta \\ x_D = x - \frac{w}{2}\sin\theta + \frac{l}{2}\cos\theta \\ y_D = y + \frac{w}{2}\cos\theta + \frac{l}{2}\cos\theta \end{cases} \tag{3}$$

In order to avoid possible collisions, during the lane-changing, if there is a vehicle or other obstacle in front of the vehicle, the vehicle needs to pay attention to the distance from the obstacle in front, to ensure that the distance between the vehicle and the obstacle in front is greater than the critical safety distance[9,10];. When the target car is reduced to a rectangular form, the vertical safety distance between the two workshops should be greater than the vernal value of half of the target car and the front car, as shown in formula (4).

$$d_s(t) \geq \left(\left(\frac{w_M}{2}\right)^2 + \left(\frac{l_M}{2}\right)^2\right)^2 + \left(\left(\frac{w_C}{2}\right)^2 + \left(\frac{l_C}{2}\right)^2\right)^2 \tag{4}$$

In the formula: w_M, l_M the length of the vehicle, the width of the vehicle, respectively; w_C, l_C is the length of the car in front of the original lane and the width of the car, respectively.

$$0 < \Delta\theta = \arctan\frac{\dot{y}(t+\Delta t) - \dot{y}(t)}{\dot{x}(t+\Delta t) - \dot{x}(t)} < \Delta\theta_{\max} \tag{5}$$

In the formula: $\Delta\theta$ is the horizontal angle that change lane in the vehicle unit time, Δt is the unit time; $\Delta\theta_{\max}$ is the maximum azimuth angle for the vehicle in unit time; $\dot{y}(t)$ is the lateral velocity; $\dot{x}(t)$ is longitudinal velocity.

The steering radius of any point in the trajectory planned in the vehicle change track plan should not exceed the vehicle's minimum turning radius. The curvature of the lane-changing trajectory:

$$K(t) = \left|\frac{\dot{x}(t)\ddot{y}(t) + \dot{y}(t)\ddot{x}(t)}{\left(\dot{x}^2(t) + \dot{y}^2(t)\right)^{\frac{3}{2}}}\right| \leq \frac{1}{R_{\min}} \tag{6}$$

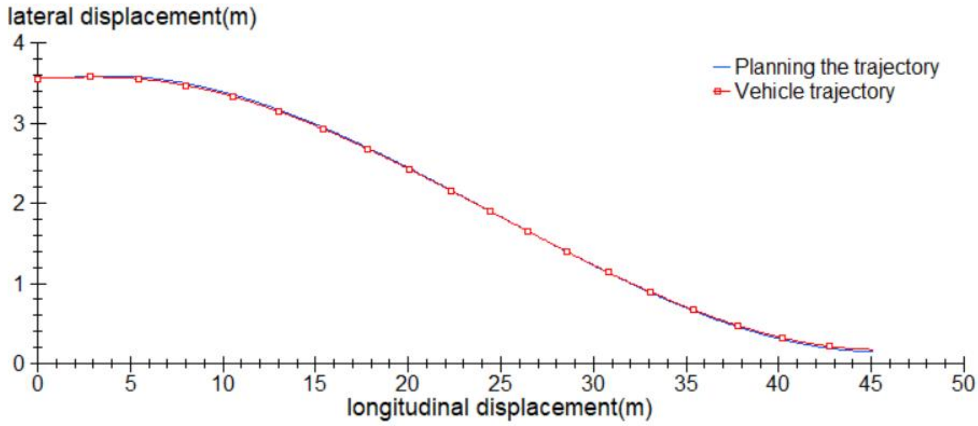
In the formula: $R_{\min}$ is the minimum turning radius for the normal driving of the vehicle, $R_{\min} = \frac{v^2}{\mu g/2}$, μ is the road attachment factor. In order to ensure the safety and comfort, the vehicle, speed, acceleration and jerk are constrained by the lane-changing process, to meet the following conditions:

$$\begin{gathered} 0 < t_1 < t_{1_{\max}} \\ v_{\min} < v(t)_m < v(t)_{\max} \\ a_{\min} < a(t)_m < a_{\max} \\ j_{\min} < j(t)_m < j_{\max} \end{gathered} \tag{7}$$

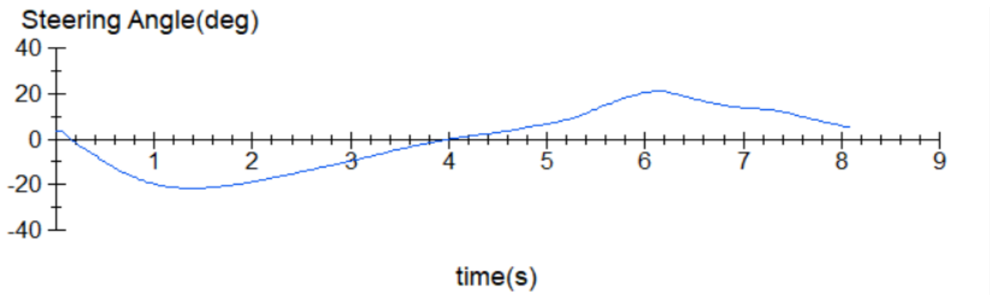
In the formula: $t_{1_{max}}$, v_{max}, a_{max}, j_{max} are the maximum time, velocity, acceleration and jerk allowed, represents. v_{min}, a_{min}, j_{min} are the minimum velocity, acceleration and jerk allowed, respectively.

4. Lane-changing trajectory simulation

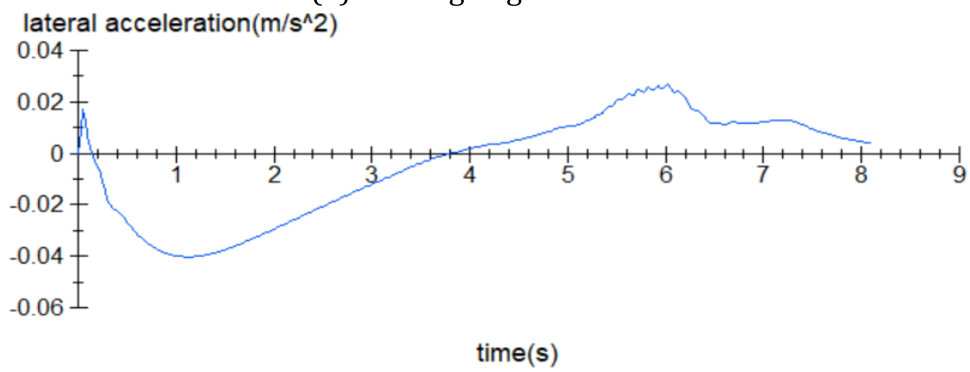
Considering that the vehicle lane-changing is affected by the front car, the track of the cosine function model and the seventh polynomial model is analyzed according to the constraints of the vehicle change. Consider the reality of small car model size has a certain difference, set the width of the car for 2 meters, length for 5 meters. The front car is moving forward at a constant speed of 17.5m/s. Write the planned track curve into Carsim's route file to simulate the vehicle's true lane-changing, as shown in Figure 3.



(a)Vehicle trajectory



(b)Steering angle of vehicle



(c)Lateral acceleration of vehicle

Figure.3 Vehicle lane-changing simulation diagram

As can be seen from Figure 3(a), the deviation between the lane changing driving trajectory of the vehicle and the target trajectory is small, less than 0.2, indicating that the lane changing driving trajectory of the vehicle in the process of completing lane changing conforms to the planned trajectory. Figure 3 (b) shows that in the process of lane change, the change interval of steering wheel Angle is [-25,25] deg, satisfying the vehicle dynamics constraint. Figure 3 (c) shows that the range of lateral acceleration values during lane changing is [-0.03,0.03]m/s^2, which can ensure the vehicle has good stability during lane changing.

In summary, it can be concluded that the key states in the process of vehicle lane changing conform to the real vehicle lane changing behavior, and the vehicle can successfully follow the planned trajectory to complete the lane changing behavior.。

5. Conclusion

Based on the analysis of vehicle lane changing trajectory and the advantages of polynomial trajectory model, such as strong continuity, multiple derivability and continuous curvature, a new idea is put forward to optimize vehicle lane changing model, and the feasibility of the lane changing model is analyzed theoretically.

The vehicle lane changing model is developing towards a more detailed and accurate direction. However, the current research on dynamic lane change planning model that can respond to the changing characteristics of environmental information in real time is still very limited, and future research should go further towards the direction of dynamic lane change trajectory planning model with real time response.

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