Research on an Intelligent Vehicle Emergency Avoidance Algorithm Based on User Behaviour Learning

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Abstract. With the development of the Internet of Vehicles and the high-precision lane-level navigation system, vehicles can receive more road details. And the systems will provide conditions for the development of the emergency avoidance function. This paper studies a vehicle automatic emergency avoidance algorithm based on user behaviour learning. The research is based on the Internet of Vehicles to obtain user driving data, generate a user database, and through the analysis of the avoidance track under the user's active operation conditions, generate a track equation or empirical formula, and the vehicle control unit executes the emergency avoidance action according to this. In the algorithm, the emergency avoidance function is defined as based on the vehicle's active safety system to avoid the event of a sudden situation, and the function will briefly disconnect the driver's partial operation when it is intervened, and the trigger conditions are set according to the trigger conditions of the parallel emergency braking function. The track equation is fitted using a sinusoidal signal, and the final output is the vehicle's front wheel angle.

Keywords: Intelligent Vehicle, Emergency Avoidance, Active Safety, User Behaviour Learning.

1. Introduction

The emergency avoidance function of autonomous vehicles is an active safety technology. The function can take emergency avoidance actions when vehicles encounter sudden obstacles. With the rapid development of the Internet of Vehicles and vehicle-road cooperation and the application of high-precision lane-level navigation systems in the pilot-assisted driving function, vehicles can receive more road information, providing conditions for the development of emergency avoidance functions.

The emergency avoidance function uses sensors. These sensors such as lidar, millimeter-wave radar, and vision sensors, can capture relevant information such as obstacle area, relative distance, relative speed, and relative acceleration of obstacles. The information is transmitted to the VCU (Vehicle Control Unit). The VCU judges and calculates based on the information provided by the sensors and other information such as vehicle speed, and then issues control instructions to control the front wheel steering angle and realize the avoidance function.

Research on high-speed emergency obstacle avoidance path planning and tracking of vehicles. Model predictive control is used for obstacle avoidance path re-planning, and the linear time-varying model predictive controller is designed for path tracking [1]. An obstacle avoidance trajectory planning method based on a fourth-order Bessel curve is proposed. SQP method is used to solve the optimal path and the optimal speed is obtained through multi-objective optimization [2]. An emergency collision avoidance system including braking and steering control is proposed [3]. The AES (Autonomous Emergency Steering) system is designed by predicting the trajectory of surrounding vehicles and considering tyre nonlinearity, which can effectively avoid collisions through simulation.

This paper, from the perspective of user behaviour learning, builds a database by obtaining the avoidance data generated under the actual operating conditions of users and uses the collation, fitting, and correction of the data in the database as the calculation source of the avoidance track to guide the vehicle control unit to complete the avoidance action.

The advantages of the user behaviour-based perspective are as follows: Learning from real cases can more truly reflect the avoidance behaviour in actual road conditions so that the algorithm is more in line with actual needs; Algorithms based on user behaviour learning can better adapt to individual differences and generate avoidance strategies more suitable for specific users or groups, improving the effectiveness and safety of avoidance; By continuously collecting and analysing users' driving data, the algorithm can continuously update and improve the user database so that the avoidance algorithm can be continuously optimized and improved over time to adapt to changing road and traffic conditions.

2. Model Construction

2.1. Function definition

In this paper, the function is definite as an emergency avoidance based on the vehicle's active safety system. The function is manifested as encountering unexpected situations while driving on the actual road, for example, when the vehicle in front suddenly breaks down with unexpected malfunction, the relative speed increases dramatically and the relative distance decreases sharply, the vehicle will perform the active avoidance function based on the information provided by the high - precision lane - level navigation system.

2.2. Model building

The construction of the emergency avoidance model mainly consists of three major parts, perception, planning and control, and execution. As shown in Figure 1, during the process of a vehicle driving on a public road, when the vehicle's sensors receive signals, the obtained information will be transmitted to the planning - and - control part. The planning - and - control part will make a judgment about whether or not the boundary conditions for function triggering are met. Meanwhile, the data accumulated in the database will serve as guidance to plan the avoidance track under this condition. After confirming that the function needs to be triggered, the control commands will be sent to the dynamic performance control module in the vehicle control unit to execute the commands and complete the entire avoidance action.

When the relative speed between the vehicle and the obstacle is less than the designed vehicle speed, the vehicle's emergency braking function will be executed. The definition of this designed vehicle speed can be designed according to different vehicle models and vehicle performances. When the relative speed between the vehicle and the obstacle is more than this designed vehicle speed, the vehicle's emergency avoidance function will be given priority. Based on the information from the high - precision lane - level navigation system and relevant sensors, the lane-changing conditions will be judged, including the direction of the lane-changing, the interference degree of obstacles in the target lane, etc., to confirm whether there is a reasonable lane - changing space to finish the execution of the active avoidance function.

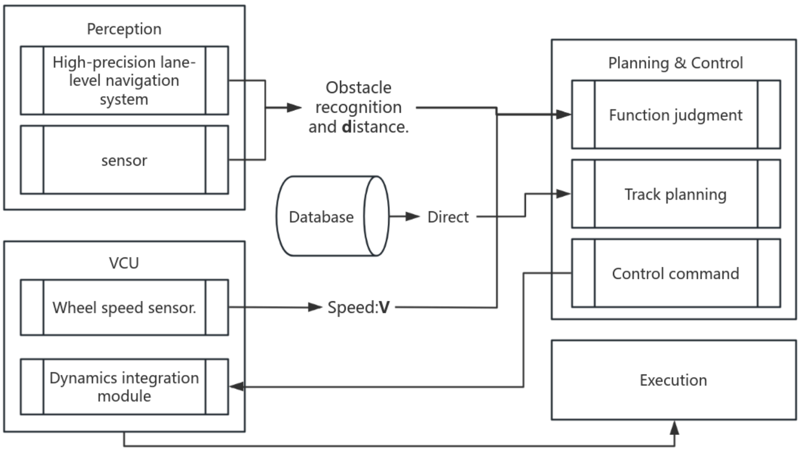

Fig 1. Model construction.

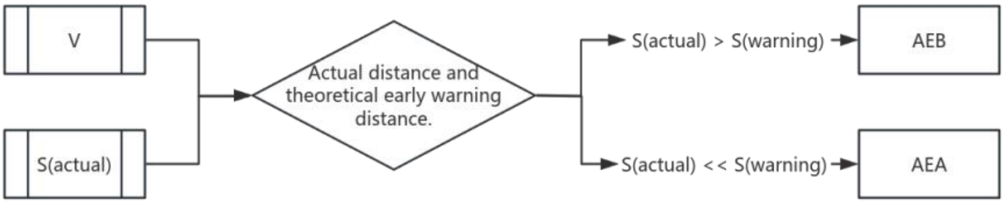

Fig 2. The choice of emergency avoidance or braking.

As shown in Figure 2, when the vehicle speed is more than the designed speed of the emergency avoidance function, substitute the actual distance of the recognized object and compare it with the early-warning distance of the emergency braking function. When the actual distance is much smaller than the early-warning distance, the trigger condition of the emergency avoidance function is met.

3. Avoidance track algorithm

3.1. User Behavior Learning

When users encountered some emergencies, identifying the obstacles on the road, they usually manipulated the steering wheel swiftly to complete avoidance. The signal input by the driver unit to the steering control mechanism is a sinusoidal signal with a relatively high frequency. To distinguish emergency avoidance behaviour from regular lane-changing behaviour, it can be obtained by marking the input duration of the signal or the frequency of the signal.

3.2. Database building

For the extracted avoidance trajectories, a coordinate system is established with the moment when the lane-change avoidance action is triggered as the origin and the vehicle's driving direction as the positive direction until the avoidance action is completed. Group them according to different initial velocities and process the curves with the same initial velocity.

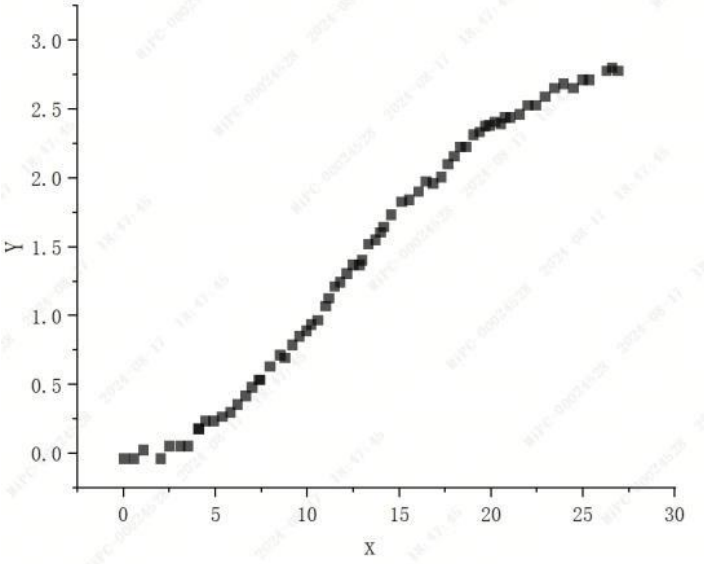

Fig 3. The coordinate points are extracted at a certain initial velocity and a certain sampling frequency.

As shown in Figure 3, it is the user's avoidance behaviour under a certain initial - velocity condition. Extract the moment when the emergency avoidance behaviour is triggered to establish the vehicle-body coordinate system x - y, extract the trajectory coordinate points at a certain sampling frequency and sort them out, and uniformly sort out all the coordinate points under this speed condition, which are recorded as:

$$(xi, yi), i=1,2,3……\text{and } xi < xi+1 \tag{1}$$

3.3. Track equation fitting

According to the coordinate points at the effective speeds extracted from the database, draw a discrete distribution diagram and perform function fitting. Since the signal input by the driving unit is a sinusoidal signal, according to the signal transmission, the signal type after modulation, filtering, and demodulation remains the same as the input signal. Therefore, the expression of the final fitting function is:

$$y=f(x)=A*\sin(B*x+C)+D; \text{ Among them, A, B, C and D are all constants.} \tag{2}$$

After fitting the track equations at each effective speed, extract the four coefficients A, B, C, and D for each group. Take the speed V as the independent variable and A, B, C, and D as the dependent variables to fit the relationships between the four coefficients and the speed, that is:

$$A=g(V),B=h(V),C=j(V),D=k(V) \tag{3}$$

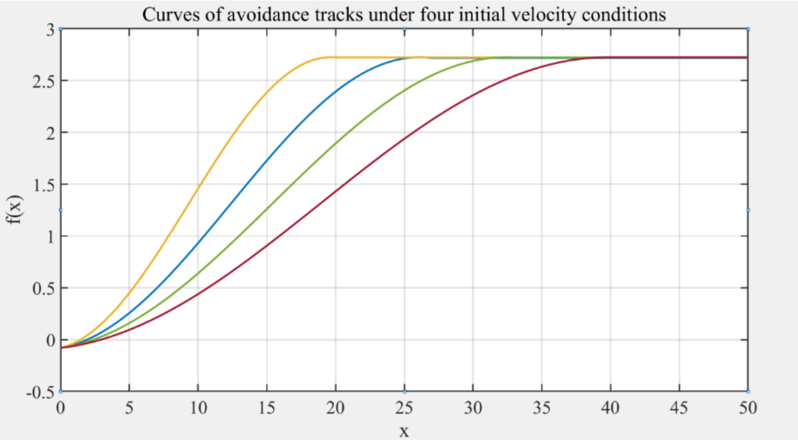

Fig 4. Avoidance tracks under four different initial velocities.

As shown in Figure 4, among the four avoidance curves with different initial velocities, the amplitudes and phases of their track equations tend to be consistent. After fitting a large amount of data, they will finally return to a certain fixed value. That is, in the avoidance tracks with different initial velocities, the amplitudes and phases are not affected by the speed. It can be seen from the curves that the coefficient of the x has the greatest influence on the entire track equation, mainly affecting the period of the sine function, so that as the speed increases, when the emergency avoidance is triggered, the distance from the obstacle now is larger. Therefore, the final track equation is:

$$Y=f(x)=A*Sin(B(Vi)*X+C) +D; \tag{4}$$

3.4. Command output

Under this model, the final output signal is the angle θ between the actual driving direction of the vehicle and the positive direction of the x-axis in the original coordinate system. In this algorithm, the deformation of the tyres and the dynamic performance of the suspension system are ignored, and the vehicle dynamic model is simplified into a two-degree-of-freedom model. Regarding the tyres as ideal rigid bodies, its expression is:

$$\theta(Vi)=A*B(Vi)*Cos(B(Vi)*X+C); \tag{5}$$

This parameter is input as a signal to the steering system control unit in the vehicle VCU (Vehicle Control Unit) and controls the steering system to complete the avoidance action.

3.5. Else limitation

After the active avoidance function intervenes, the possibility of the driver's operation of the steering wheel, brake pedal, and accelerator pedal is briefly disconnected. For the convenience of drivability development and adjustment, electric vehicles usually adopt electronic steering and decoupled braking systems. To avoid the driver over - manipulating the steering mechanism and pedals due to panic when this function is triggered, the vehicle will briefly disconnect the interaction function between the driver and the driving unit and resume it after the avoidance action is completed.

4. Simulation

4.1. Case condition input

To verify the effectiveness of the emergency avoidance algorithm, take an electric vehicle equipped with a lidar and a high-precision lane-level navigation system as an example for verification. The test scenario is as follows: on an open and closed road section, during the driving process, the vehicle in front suddenly changes lanes and cuts out to the right, exposing the faulty vehicle stationary in the current lane in the field of vision. Currently, there is sufficient lane-changing space in the adjacent lane on the left. The emergency avoidance algorithm is run on a computer platform installed with Matlab R2018b, and the vehicle test boundaries are as Table 1:

Table 1. Settings of Verification Parameters for Emergency Avoidance Algorithm.

Parameter	Unit	Value
Speed, V	Kph	75
Distance to obstacle,d	m	20

4.2. Avoidance algorithm verification

4.2.1. Condition judgment

The following are the results of the preliminary test of the vehicle's emergency braking function. Fit the relationship between the warning distances of the emergency braking function based on these test results, as shown in Table 2:

Table 2. The warning distance of the emergency braking function at different vehicle speeds.

The warning distances of the AEB (Autonomous Emergency Braking) function of this electric vehicle at different vehicle speeds.															
Speed	60			70			80			90			100		
Warning distance	14.35	21.3	19.42	24.94	27.3	28.4	32.4	32.7	32.99	39.9	39.15	440.19	52.4	50.78	49.53

According to the input vehicle speed V = 75 kilometres per hour. After estimation, the theoretical emergency braking warning distance is approximately 28 meters. That is, Sactual < Swarning and the emergency avoidance function will be executed preferentially. According to the space information provided by the high-precision lane-level navigation system and sensors, the vehicle will change lanes to the left when executing the emergency avoidance function.

4.2.2. Avoidance Algorithm Simulation

According to the input conditions, by the trajectory equation under V = 75kph in the database, the vehicle performs the avoidance action, as shown in Figure 5:

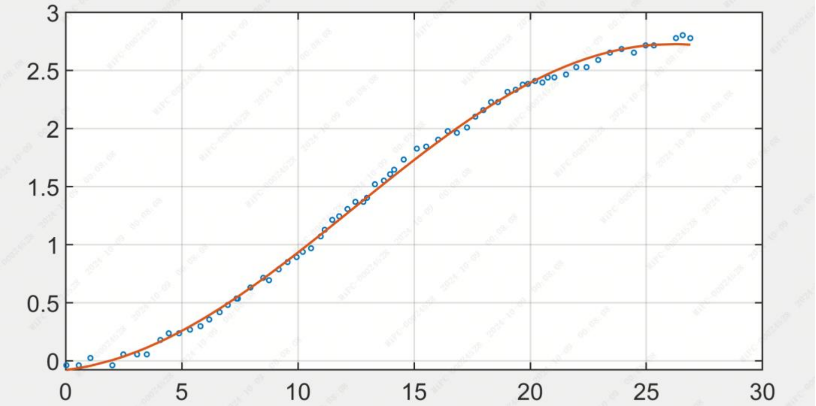

Fig 5. The track equation of the emergency avoidance function.

During the avoidance process, the opening of the accelerator pedal is 0, and the vehicle coasts naturally in the forward gear to complete the avoidance. Throughout the process, there is no additional power input, no additional braking force input, and no additional steering signal input.

The track equation is:

$$y=1.41*\mathrm{Sin}\ (0.114*x-1.42) + 1.314; \tag{6}$$

Also, the angle θ between the actual driving direction of the vehicle and the positive direction of the x-axis is:

$$\theta=\arctan\ [0.16*\mathrm{Cos}(0.114*x-1.42)]; \tag{7}$$

5. Conclusion

The boundary conditions of this algorithm still have some space to supplement and improve, such as the basic lane information including lane width, lane adhesion coefficient, etc., which may bring improvement and optimization with the development of a high-precision lane-level navigation system in the future.

In the boundary content mentioned by the algorithm in this paper, the execution conditions of the function are relatively ideal. For example, when considering the output of the algorithm, the direct output of the front wheel Angle data is carried out on the premise that the tyre is regarded as a rigid body and the steering system is designed as an ideal Ackermann relation. However, different tyres have different tyre data. For example, tyre size, tyre roll resistance coefficient, tyre pressure, and physical characteristics of the tyre as an elastic body will have a certain impact on the functional performance of the real car, so the algorithm should be modified according to the chassis adjustment level of the whole vehicle in the process of use.

When considering lane change, the algorithm assumes that the vehicle is in the middle state of the current road, but the vehicle will not be in the absolute middle state all the time when the real vehicle is running, so the degree of the centre of the vehicle in the lane should be corrected in the collision avoidance equation.

The algorithm provides an emergency avoidance calculation method based on users' behaviour learning. There is still much space for improvement in the description of the algorithm in this paper. For example, the expression of the trajectory equation ideally considers that the trajectory equation is composed of a sinusoidal function containing amplitude, phase and other characteristics. But the real relation is needed to research further. In addition, the algorithm does not mention the requirement of the function execution time. Ideally, this paper believes that the vehicle travels through the trajectory equation at a constant speed during collision avoidance. However, combined with the objective situation, the rolling resistance coefficient of the tyre ensures that the vehicle will not keep a constant speed in the horizontal direction during collision avoidance, so the algorithm should involve the influence of the deceleration caused by rolling.

References

[1] Cao Changsheng, Cao Haotian: <<Intelligent vehicle obstacle avoidance trajectory planning method based on Bezier curve>>, <<Application of Electronic Technique>>, 2024, Vol. 50, No. 2.

[2] Shen Yue, Chen Jing, Zhou Zihan, Yang Da: <<"Cooperative avoidance model of dynamic obstacles for autonomous vehicles in the environment of Internet of Vehicles>>, <<Journal of Transportation Engineering and Information>>, 2021, Vol. 19, No. 4.

[3] Wang Jian, Wang Jinbo, Peng Xin, Qiu Xuyun, Li Aijuan: <<Vehicle trajectory planning method based on lane-changing critical conditions>>, <<Master's Degree Thesis of North China University of Technology>>, June 2024.

[4] Janghee Park, Dongchan Kim, Kunsoo Huh: <<Emergency Collision Avoidance by Steering in Critical Situations>>, <<International Journal of Automotive Technology>>, 2021, Vol. 22, No. 1.

[5] Zhang Lin: <<Research on trajectory planning of autonomous vehicles and its collaborative optimization method with avoiding emergency vehicles>>, <<Master's Degree Thesis of North China University of Technology>>, June 2024.

[6] Hao Wei, Liang Cong, Zhang Zhaolei, Lü Nengchao, Yi Kefu:<<Cooperative lane changing strategy for avoiding emergency vehicles under vehicle-road cooperation>>,<<Journal of Transport Information and Safety>>,2022, Vol. 40, No. 4.

[7] Xu Yuan: <<Research on emergency obstacle avoidance system for automobiles at high speed>>, <<Machinery Design & Manufacture>>, 2019, No. 9.

[8] Wang Zhihan, Lin Li, Han Donghui, Li Ruicheng: <<Application of unmanned driving technology based on automatic avoidance>>, <<Heilongjiang Science>>, 2023, Vol. 14, No. 16.

[9] Huang Fengrong, Yi Bohang, Wang Xu, Liu Qinglin, Wang Wensen: <<Vehicle inertial navigation method based on deep learning and motion state recognition>>, <<Journal of Chinese Inertial Technology>>, 2022, Vol. 30, No. 5.

[10] Rang Binbin, Shi Wei: <<Design and implementation of autonomous navigation and obstacle avoidance system for driverless vehicles>>, <<Computer Knowledge and Technology>>, 2022, Vol. 18, No. 32.

[11] Christian Hernandez, Daniel Paredes, René Játiva E :<< Design and Implementation of an autonomous vehicle with LIDAR-based navigation>>, <<2020 International Conference on Mechatronics, Electronics and Automotive Engineering (ICMEAE)>>.

[12] Tengchan Zeng, Omid Semiari, Walid Saad, Mehdi Bennis :<< Joint Communication and Control System Design for Connected and Autonomous Vehicle Navigation>>, <<IEEE Xplore>>2019.