Edge Computing Based Two-Stage Emergency Braking in Autonomous Driving

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Abstract. Emergency braking is a key technology in autonomous driving to prevent collision accidents. In this paper, we propose an edge computing based two-stage emergency braking method (TSEB), which can bring passengers more comfortable experience with emergency braking while avoiding collision. In TSEB, the initial deceleration rate is figured out at the first time point, in terms of motion parameters of the moving vehicle and the moving or static obstacle, and used to set the braking force for the first-stage braking, which can at least avoid serious collision. The second deceleration rate is figured out in terms of the parameters at the second time point and implemented on the vehicle by increasing the braking force in the second-stage braking. With the second-stage braking, the vehicle can stop at a safer distance to the obstacle while the passengers do not feel too much deceleration. The performance of TSEB is evaluated on the simulation platform composed of Prescan, Simulink and Matlab. TIS sensors of long distance and short distance are used to detect the distance between the vehicle and the obstacle.

Keywords: Emergency braking · Autonomous driving · Edge computing

1 Introduction

Emergency braking, as a basic function in autonomous driving, is used to avoid collision accidents, which is critical to vehicle and public safety. V2X in the Internet of Vehicles obtains the information of the stored vehicle through the cloud, and analyzes the data of the vehicle to evaluate the current driving situation, location situation and safety information of the vehicle. When an emergency occurs, relying on the cloud for emergency hedging, the length of the delay is difficult to ensure the success of hedging, and the use of edge computing can achieve extremely low latency and ensure the timely avoidance of the car [1–3].

The development of edge computing is widely used in real-time data processing of public safety, virtual reality, industrial Internet of Things, smart homes,

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smart cities, and intelligent connected cars and autonomous driving. One of the characteristics of edge computing is the reduction of latency [4]. In edge computing based emergency braking, sensors installed on the vehicles can be used to identify the obstacles in front and to sense the relative distance between the moving vehicle and the obstacles. The obtained parameters are used as input for edge computing to avoid collision [5]. Compared to cloud based decision making, edge computing based emergency baking can perform better in agility and reliability [6].

As a branch of cloud computing, edge computing can marginalize data and make it more efficient and convenient. In this project, edge computing is used. Firstly, information can be put into the cloud as a part of the cloud database to increase the storage data of vehicle networking applications in the later stage. The second point is that when there is a problem with the vehicle identification system, it can be observed and controlled through the cloud as an emergency treatment. The last point is that edge computing has the characteristics of low latency, and can process data quickly, consistent with small devices.

In this paper, we propose an edge computing based two-stage emergency braking method (TSEB), which can bring passengers more comfortable experience with emergency braking while avoiding collision. In TSEB, the initial deceleration rate is figured out at the first time point, in terms of motion parameters of the moving vehicle and the moving or static obstacle, and used to set the braking force for the first-stage braking, which can at least avoid serious collision. The second deceleration rate is figured out in terms of the parameters at the second time point and implemented on the vehicle by increasing the braking force in the second-stage braking. With the second-stage braking, the vehicle can stop at a safer distance to the obstacle while the passengers do not feel too much deceleration. The performance of TSEB is evaluated on the simulation platform composed of Prescan, Simulink and Matlab. TIS sensors of long distance and short distance are used to detect the distance between the vehicle and the obstacle.

2 Two-Stage Emergency Braking

In this section, the processes of collision and emergency braking are formulated and the two-stage emergency braking method (TSEB) is described.

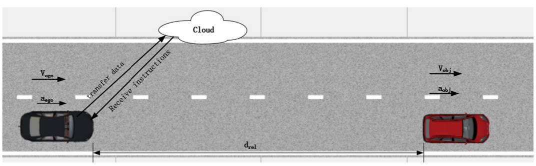

Fig. 1. Top view of parameter identification.

Assume a vehicle moving at velocity v_{ego} and acceleration rate a_{ego} is closing to an obstacle in front moving at v_{obj} and acceleration rate a_{obj}, as Fig. 1 shows. Collision will happen when the following equation holds,

$$v_{\text{ego}}t + \frac{1}{2}a_{\text{ego}}t^2 = v_{\text{obj}}t + \frac{1}{2}a_{\text{obj}}t^2 + d_{\text{rel}}, \tag{1}$$

where d_{rel} is the distance between the moving vehicle and the obstacle at the time point when v_{ego}, a_{ego}, v_{obj} and a_{obj} are measured. (1) can be written as

$$f(t) = 0 \tag{2}$$

where $f(t)$ is a quadratic function of t

$$f(t) = a_{\text{rel}}t^2 + 2v_{\text{rel}}t - 2d_{\text{rel}}, \tag{3}$$

with

$$a_{\text{rel}} = a_{\text{ego}} - a_{\text{obj}}, \tag{4}$$

$$v_{\text{rel}} = v_{\text{ego}} - v_{\text{obj}}. \tag{5}$$

If the vehicle and the obstacle keep their current speeds and acceleration rates,

1) in the case of $a_{\text{rel}} > 0$, *i.e.*, $a_{\text{ego}} > a_{\text{obj}}$, the vehicle will collide with the obstacle at the time point t_{c}

$$t_{\text{c}} = \frac{-v_{\text{rel}} + \sqrt{v_{\text{rel}}^2 + 2a_{\text{rel}}d_{\text{rel}}}}{a_{\text{rel}}}; \tag{6}$$

2) in the case of $a_{\text{rel}} = 0$, *i.e.*, $a_{\text{ego}} = a_{\text{obj}}$, the collision time point is

$$t_{\text{c}} = \frac{d_{\text{rel}}}{v_{\text{rel}}}; \tag{7}$$

3) in the case of $a_{\text{rel}} < 0$, *i.e.*, $a_{\text{ego}} < a_{\text{obj}}$, $v_{\text{rel}} > 0$ and $-v_{\text{rel}}^2/a_{\text{rel}} \geq 2d_{\text{rel}}$, the collision time point is

$$t_{\text{c}} = \frac{-v_{\text{rel}} - \sqrt{v_{\text{rel}}^2 + 2a_{\text{rel}}d_{\text{rel}}}}{a_{\text{rel}}}; \tag{8}$$

4) in the case of $a_{\text{rel}} < 0$, *i.e.*, $a_{\text{ego}} < a_{\text{obj}}$, and $-v_{\text{rel}}^2/a_{\text{rel}} < 2d_{\text{rel}}$, we have that $f(t) < 0$ for all $t \geq 0$ and thus there is no risk of collision.

For avoiding the foreseen collision which would happen at the time point T_0 in Case 1–3, deceleration is to be enforced to the vehicle by braking. Denote the deceleration rate by b_{ego}. In terms of (3), we have the function

$$g_1(t) = -(b_{\text{ego}} + a_{\text{obj}})t^2 + 2v_{\text{rel}}t - 2d_{\text{rel}}. \tag{9}$$

In the light of Case 4, to avoid collision, b_{ego} should be set so as to

$$b_{\text{ego}} > \frac{v_{\text{rel}}^2}{2d_{\text{rel}}} - a_{\text{obj}}. \tag{10}$$

In our TSEB method, the sensors on the vehicle measure the speeds and acceleration rates of the vehicle and the obstacle and their distance, denoted by $v_{\text{ego},1}$, $a_{\text{ego},1}$, $v_{\text{obj},1}$, $a_{\text{obj},1}$ and $d_{\text{rel},1}$, when an obstacle in front is sensed. If there is a risk of collision, the first deceleration rate $b_{\text{ego},1}$ is calculated as

$$b_{\text{ego},1} = \frac{v_{\text{rel},1}^2}{2(d_{\text{rel},1} + \Delta d)} - a_{\text{obj},1} \tag{11}$$

where $\Delta d \geq 0$ is a relaxing distance value, and

$$v_{\text{rel},1} = v_{\text{ego},1} - v_{\text{obj},1} \tag{12}$$

At the first stage of emergency braking, the braking force F_1 which can generate the deceleration rate $b_{\text{ego},1}$ is enforced on the vehicle.

After time Δt, the sensors measure the speeds and acceleration rates of the vehicle and the obstacle and their distance again, denoted by $v_{\text{ego},2}$, $a_{\text{ego},2}$, $v_{\text{obj},2}$, $a_{\text{obj},2}$ and $d_{\text{rel},2}$. The vehicle will stop at the time point with the time point when the sensors do the second measurement as the reference time point,

$$t_{\text{ego},2} = \frac{v_{\text{ego},2}}{b_{\text{ego},2}}. \tag{13}$$

Then, if there is risk of collision, the second deceleration $b_{\text{ego},2}$ is calculated as

$$b_{\text{ego},2} = \max\left(\frac{v_{\text{ego},2}^2}{2(d_{\text{rel},2} - \Delta d_s)} - a_{\text{obj},2}, \quad \frac{-v_{\text{ego},2} a_{\text{obj},2}}{v_{\text{obj},2}}\right) \tag{14}$$

where Δd_s is the required minimum distance between the vehicle and the obstacle during the emergency braking process.

The second term in the bracket of (14) comes from the inequality

$$t_{\text{ego},2} \geq \frac{v_{\text{rel},2}}{b_{\text{ego},2} + a_{\text{obj},2}} \tag{15}$$

At the second stage of emergency braking, the braking force F_2 which generate the deceleration rate $b_{\text{ego},2}$ is enforced on the vehicle, which means the incremental braking force $\Delta F = F_2 - F_1$ is implemented.

The TSEB method is used to increase the braking force in two steps, which can improve the passenger's experience on inertia and thus increases the comfort of the ride.

3 Simulation Platform

3.1 Control Principle

The automatic emergency braking system is a cyclic closed-loop system composed of a perception system, an operation control system and an execution system. The system is based on real-time detection data of on-board TIS sensors, and uses target feature extraction algorithms to calculate distance and relative speed to the front target [7,8]. Operation control calculates the data information, performs function judgment, and performs three-level operation of the component to evaluate whether there is a collision. Danger; According to the collision danger level, the actuator prompts an alarm and controls the braking module to make an emergency braking response. The control principle diagram is shown in Fig. 2.

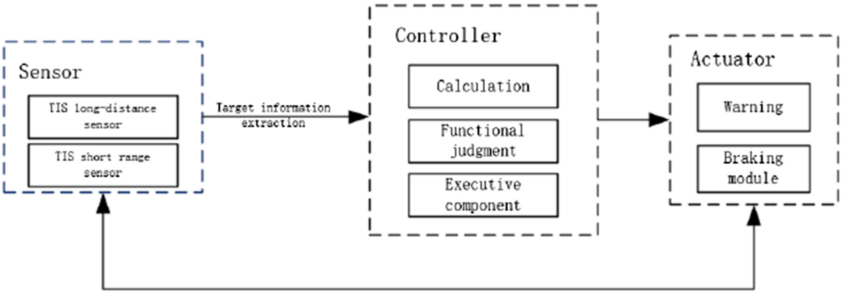

Fig. 2. Control principle diagram.

3.2 Simulation Scheme

The design of the main simulation scene includes the car, obstacles, track design and sensor module, *etc.* The scene information is obtained through the sensor environment perception. The sensed data is transmitted to the module of the control decision algorithm, the control command is given to the actuator by the algorithm and the actuator controls the engine, rotation, steering structure and brake structure module, etc. Finally the state of the vehicle is transmitted to the scene to form a closed loop.

In our simulation, a 5-lane environment is used. A white obstacle vehicle is set in the middle lane. The movement trajectory of the moving car is set and a simulated down-view human eye perspective is set directly above the car for observation.

TIS sensors of long distance and short distance are installed on the car [9]. The long distance sensor is used to detect the distance of the obstacle vehicle in front, and the short distance is used to detect the range of obstacles. As shown in Fig. 3.

In the prescan system, the car dynamics model is set to facilitate the subsequent operation of the brake system of the car dynamics module in MATLAB. The .slx file is compiled and generated based on the characteristics of prescan and designed in MATLAB. The .slx file includes the corresponding car model generation, TIS sensor module, dynamics model module, road control module,

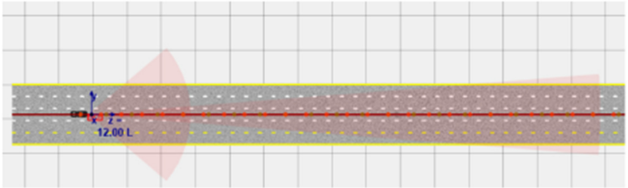

Fig. 3. TIS sensor scene settings.

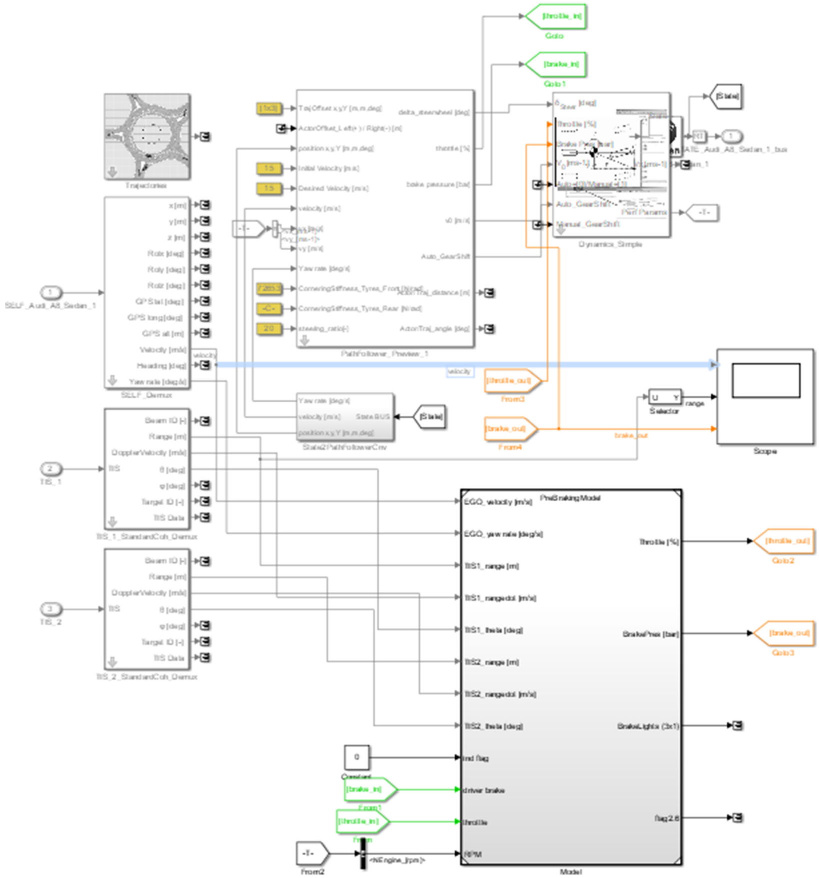

Fig. 4. Configuration interface

and the most important plug-in design parking control module [9]. Figure 4 shows the designed configuration interface.

The corresponding car information is input into the corresponding interface, and the range data recognized by the sensor is connected to the corresponding parking analysis module to analyze when to start the operation of the braking module. The parking module is directly connected to the car's dynamics module. The braking, steering angle and gear settings are controlled to achieve parking of the car.

4 Simulation Results

By running the program, we can observe in 3Dviewer that the car travels smoothly on the road according to the setting. When the sensors detect the obstacle, it prompts warning and starts the emergency braking process with TSEB.

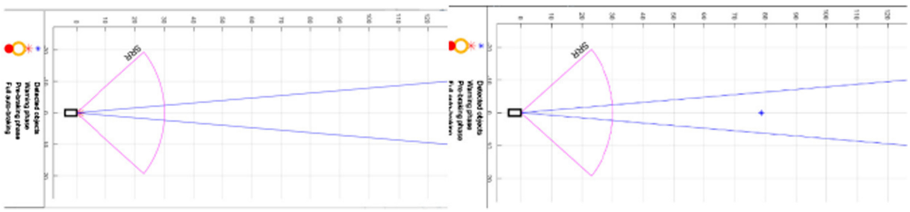

Fig. 5. Top view of the car sensor.

Figure 5 is the top view of the car sensor. The pink area is the short-range sensor detection range, and the blue is the long-range detection range. The blue star is the detected object.

On the GUI, as shown in Fig. 6(a), the speed, braking force, and angle of rotation of the car at a constant speed are presented.

Figure 6(b) shows the scenario that the vehicle detects the obstacle at the beginning, and starts to warn that braking is required. The first stage emergency braking is executed at this moment and the braking force F_1 is enforced. The speed of the car starts to decrease gradually.

Figure 6(c) shows that the second level of braking is started, the braking force reaches hundred percent, and the speed of the car begins to drop more quickly.

Figure 6(d) shows the completion of braking. The braking force is displayed as the maximum. The speed of the car is zero and the angle of rotation is also zero.

Figure 7, Fig. 8, Fig. 9 show the comparison simulation results of TSEB and One-Stage Emergency Braking. In the Fig. 7, it shows the speed curve of the trolley during the whole process. We can see that the speed of the trolley has two different accelerations in TSEB to accelerate the speed of the trolley, while OSEB accelerates to zero with the same acceleration. Figure 8 shows the distance between the car and the obstacle detected by the TIS sensor. We can see that the final distance from the obstacle in OSEB is about 2.9 m, and the final distance from the obstacle in the TSEB is about 2.3 m.Fig. 9 shows the amount of braking force obtained by the car. We can see that there is a stepped increase in braking

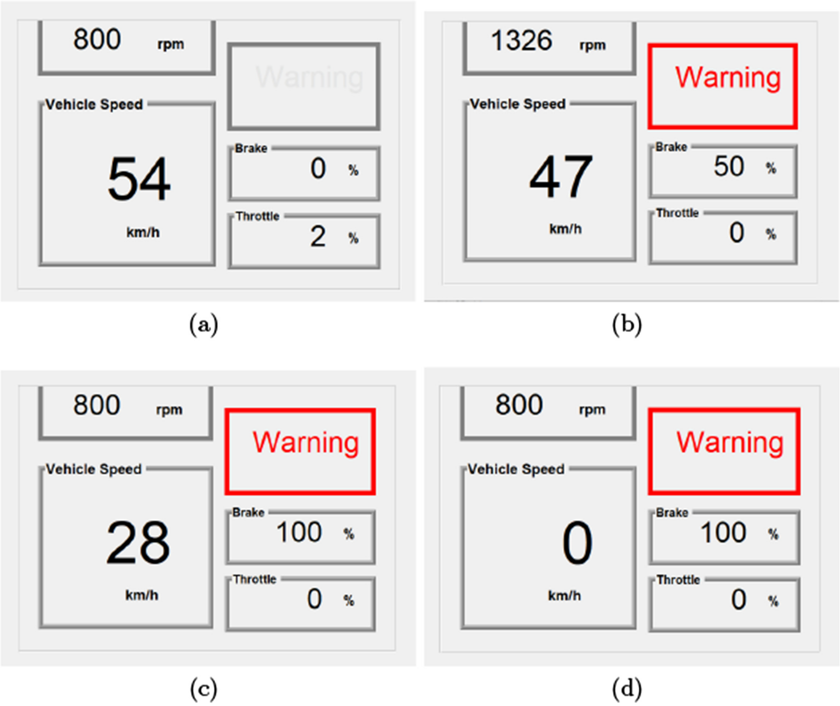

Fig. 6. TSEB

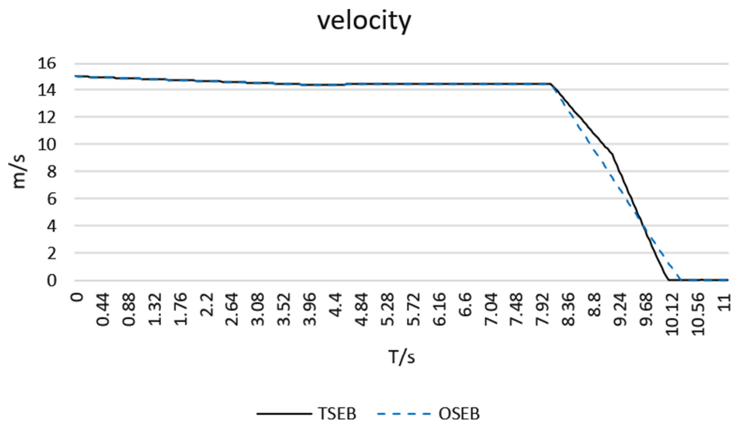

Fig. 7. Simulation of speed.

force in TSEB, so that the car gets two different accelerations to decelerate. The second braking starts from 9.1 s, and the braking force is 150 N. In OSEB, the one-time braking maximization is used to achieve the ability to quickly brake the car. In OSEB, the function is realized only by a single braking, which makes

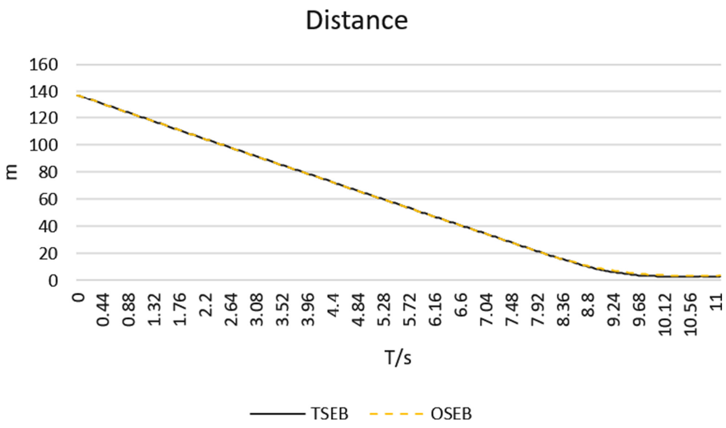

Fig. 8. Simulation of distance.

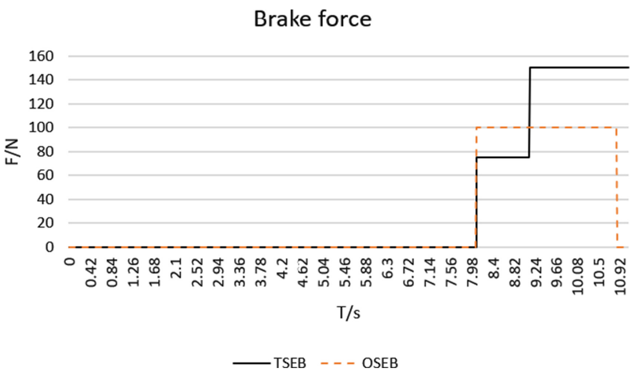

Fig. 9. Simulation of braking force.

the comfort experience of the vehicle and the driver relatively low. The driver feels that the parking inertia will have a larger forward inertia, thereby reducing the comfort of the experience.

For the driver in the process of driving at a constant speed, the body has always maintained the same speed as the vehicle. When the braking starts, the vehicle is given a small braking force, so that the vehicle obtains a small deceleration and begins to decelerate initially. In this process, the driver starts driving at the same speed as the vehicle. When the vehicle starts to decelerate, it has a forward momentum. Since the force is relatively small compared with the force of one braking, the driver will feel less momentum.

In the secondary braking, the braking is performed based on the first braking, so the relative braking force should be the difference between the two braking. After the first braking, the driver should recognize that emergency braking has begun, so he will be more psychologically prepared for the second braking. Compared with a single braking, the driver feels a greater continuous deceleration and is triggered suddenly without preparation. The shock felt will be greater than that of the secondary braking, so the secondary braking will be relatively more comfortable.

5 Conclusion

In this paper, we propose an edge computing based two-stage emergency braking method (TSEB), which can bring passengers more comfortable experience with emergency braking while avoiding collision. In TSEB, the initial deceleration rate is figured out at the first time point, in terms of motion parameters of the moving vehicle and the moving or static obstacle, and used to set the braking force for the first-stage braking, which can at least avoid serious collision. The second deceleration rate is figured out in terms of the parameters at the second time point and implemented on the vehicle by increasing the braking force in the second-stage braking. With the second-stage braking, the vehicle can stop at a safer distance to the obstacle while the passengers do not feel too much deceleration. The performance of TSEB is evaluated on the simulation platform composed of Prescan, Simulink and Matlab. TIS sensors of long distance and short distance are used to detect the distance between the vehicle and the obstacle.

Regarding the choice of braking force, it is temporarily impossible to fully simulate the braking effect of the human body. Only a simple two-stage braking is used as an example to show that multi-stage braking will improve the comfort of emergency braking, which can be further studied in the future. Begin by gradually increasing the braking force, but gradually increasing the braking force will also mean expanding the detection range and further increasing the detection threshold, which will make the distance between the vehicles farther and not suitable for practical applications. This needs to be solved with further research.

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