A research on evaluation and development of single-pedal function for electric vehicle based on PID

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Abstract. The pure electric vehicle can be driven and regenerative braked by motor, so the development of single-pedal function which is realised by motor torque and evaluation on drivability of electric vehicle is researched in this paper. Driver can launch, accelerate, brake even park only by operating accelerator pedal. Single-pedal function is researched based on PID and Co-simulation using Matlab/Simulink and Carsim. Evaluation standards and indexes about drivability of electric vehicle with sing-pedal are developed which is implemented on a real vehicle. The research can support the optimization and development of single-pedal function for electric vehicle.

1. Introduction

1.1. Introduction of single-pedal

The so-called single pedal is not without a brake pedal, but a driving mode completely different from the traditional driving habits, as shown in Figure 1. As the name implies, driver can only operate the accelerator pedal to launch, accelerate, decelerate, brake and even stop the vehicle, which is suitable for driving in urban congestion and mountain road. At the same time, when the driver has an emergency or precise braking request, it can still be achieved by operating the brake pedal. The earliest single-pedal function was developed by BMW and applied to i3. Subsequently, various OEMs have developed similar functions, such as E-Pedal applied to LEAF by Nissan and ECO applied to NOTE. In order to realize driving and braking at the same time through the accelerator pedal, it is necessary to maintain a certain accelerator pedal position in the actual driving under the single-pedal
mode, which is also different from the characteristics of traditional driving habits. Single-pedal can provide a new driving experience for the driver, and because the pure electric vehicle is completely driven by motor, in terms of energy recovery effect it can be equivalent to fully decoupling regenerative braking system, but at the same time, the disadvantage of single-pedal is that it is not suitable for continues long-time driving, because it will increase the operation fatigue of the driver's right foot.

1.2. PID

PID control is one of the earliest developed control strategies. Because of its simple algorithm, good robustness and high reliability, it is widely used in process control and motion control, especially in the system which can establish accurate mathematical model. Digital PID control is a commonly used control method in the production process. The proportion (P), integral (I) and differential (D) of the deviation are combined to control the object, so it is called PID controller.

\[
\begin{align*}
\text{Figure 2. PID control principle}
\end{align*}
\]

The typical PID control formula is as follows,

\[
u(t) = K_P e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_D \frac{de(t)}{dt}
\]

Among them, \( u(t) \) is the output by controller; \( e(t) \) is the deviation signal, which is equal to the difference between the input signal and the output signal; \( K_P \) is the scale factor (corresponding to parameter P); \( T_i \) is the integral time constant (corresponding to parameter I); \( T_D \) is the differential time constant (corresponding to parameter D). Digital PID control algorithm is usually composed of position PID control algorithm and incremental PID control algorithm.

Position PID control formula is as follows,

\[
u(k) = K_P e(k) + K_I \sum_{i=0} e(i) + K_D [e(k) - e(k-1)]
\]

Among them, \( e(k) \) is the difference of target and the current value. \( \sum_{i=0} e(i) \) is error accumulation. \( e(k) - e(k-1) \) is the difference of current error and last error.

That is to say, the position PID is the deviation between the actual position of the current system from the expected position to be achieved. PID control is carried out because there is error integral \( \sum_{i=0} e(i) \) has been accumulating. That means, the current output \( u(k) \) is related to all the past states, and the accumulated error value is used; the output \( u(k) \) corresponds to the actual position of the actuator, once the control output is wrong, the large change of \( u(k) \) will cause the large change of the system. When the integral term of position PID reaches saturation, the error will continue to accumulate under the integral effect. Once the error starts to change in the reverse direction, the system needs to exit from the saturation area for a certain time. Therefore, when \( u(k) \) reaches the maximum and minimum, the integral effect should be stopped, and there should be integral limit and output limit. Therefore, when using position PID, we usually use PD control directly.

Incremental PID control formula is as follows,
\[ \Delta u(k) = u(k) - u(1-1) \]
\[ = K_p[e(k) - e(k-1)] + K_I e(k) + K_D[e(k) - 2e(k-1) + e(k-2)] \]

Among them, \( e(k) - e(k-1) \) is the difference of current error and last error. \( e(k) \) is the difference of target and the current value. \( e(k) - 2e(k-1) + e(k-2) \) is this error - 2 * last error + error before the last error.

The incremental PID can be well seen from the formula. Once \( K_p, K_I, K_D \) is determined, as long as the deviation of the measured value before and after three times is used, the control amount \( \Delta u(k) \) can be calculated from the formula, which corresponds to the increment of the position error in recent times, rather than the deviation corresponding to the actual position without error accumulation, that means, the increment PID does not need to be accumulated. The determination of control increment \( \Delta u(k) \) is only related to the last three sampling values, and it is easy to obtain better control effect by weighting processing, and when the system has problems, incremental control will not seriously affect the work of the system. Incremental PID is the increment of position PID. At this time, the output of the controller is the difference between the position values calculated at the two adjacent sampling times. The result is increment, that means, the control amount needs to be increased based on the last control amount. The position PID control algorithm is used in the research, and the single pedal control function is developed in a pure electric vehicle, and a vehicle test verification and evaluation are carried out.

2. Simulation

2.1. The simulation model based on CarSim

| Table 1. Vehicle parameters |
|-----------------------------|
| **Items**                   | **Parameters** | **Unit** |
| Vehicle                     | Curb weight    | 1760 kg  |
|                             | Driving type   | Front drive |
|                             | Steering       | EPS      |
| Motor                       | Type           | PM       |
|                             | Peak power     | 140 kW   |
|                             | Peak speed     | 12000 rpm |
| Battery                     | Type           | Li       |
|                             | Nominal voltage| 350 V    |
| Reduction                   | Ratio          | 8.28     |
| Wheel                       | Type           | 245/45 R20 |
|                             | Rolling radius | 0.354 m  |
CarSim is a software developed by MSC (Mechanical Simulation Corporation). The CarSim model can simulate the response of the vehicle to the driver, the road and the aerodynamic inputs. It is mainly used to predict and simulate the drivability, braking, dynamic and economy of the whole vehicle. At the same time, it is widely used in modern vehicle control system development. CarSim can easily and flexibly define the test environment and test process, define the characteristic parameters and characteristic files of each system of the whole vehicle in detail, and observe the simulation results in the form of graph curve and 3D animation; including graphical data management interface, vehicle model solver, drawing tool, 3D animation playback tool, power spectrum analysis module, and the program is stable and reliable. Aiming at a pure electric vehicle model, this paper establishes the corresponding CarSim vehicle model and environmental road model, as shown in Figure 3, and the vehicle parameters are shown in Table 1.

2.2. The co-simulation model

The single pedal control model is built in Matlab / Simulink, and the co-simulation model with CarSim is shown in Figure 4. The control module mainly consists of two parts, driving control torque calculation and parking control torque calculation. Among them, the calculation of driving control torque is shown in Figure 5, which is mainly used to calculate the driver's request torque in the normal driving process. The driver's request torque is calculated through the 2-dimensional map table input by
vehicle speed and accelerator pedal position. The design of the torque map ensures that in the driving process, when the driver releases the accelerator pedal under a certain position, the output driving torque of vehicle changes into braking torque.

**Figure 5. The calculation of driving torque**

When driver releases the accelerator pedal completely, the vehicle will slow down and finally parked. The calculation of parking control torque mainly includes parking calculation enabling module and parking torque calculation module, as shown in Figure 6. Among them, the parking calculation enabling module determines whether it needs to calculate the parking torque according to the current speed and the opening of the accelerator pedal, that means, when the speed is less than 5km/h and the opening of the accelerator pedal is equal to 0%, then parking torque calculation module is enabled. According to the current speed and slope signal, the parking torque calculation module calculates the current parking torque to ensure the vehicle parking.

**Figure 6. The calculation of parking torque**

In the process of driving, when the accelerator pedal is fully released, in order to ensure that the motor torque can finally park vehicle on a certain slope of the road, the sum of preloading torque and PI torque is used to calculate the final parking torque. As shown in Figure 7, the parking torque calculation includes three parts: preloading torque calculation based on the slope, proportion torque calculation and integral torque calculation. Among them, the proportion torque is product of scale factor and the difference between target speed and current speed; the integral torque is the product of integral factor and the integral of difference between target speed and current speed.
2.3. The simulation results

The simulation results from figure 8, figure 9 and figure 10 shows that, when vehicle slides from high speed to parking on different slope (±5%, 0%) road, T1 represents the opening range of acceleration pedal generating driving torque, T2 represents the opening range of the acceleration pedal generating regenerative torque, and T3 represents the length of time during parking control stage.

![Figure 8. The simulation result on 5% slope road](image)

![Figure 9. The simulation result on flat road](image)
When the accelerator pedal is released on 5% slope road, the brake control opening range T2 of the accelerator pedal of vehicle is about 30%. When the accelerator pedal is fully released and the vehicle speed is less than 5km/h, T3 is about 0.3s. On a flat road, the opening range of the accelerator pedal brake control T2 is about 25%. When the accelerator pedal is fully released and the vehicle speed is less than 5km/h, T3 is about 0.5s. When the accelerator pedal is released on -5% slope road, the brake control opening range T2 of the accelerator pedal of the whole vehicle is about 10%. When the accelerator pedal is fully released and the vehicle speed is less than 5km/h, T3 is about 0.5s.

It can be seen that on different slopes, driving and braking can only achieve by the accelerator pedal. The range of brake control range of single pedal increases with the increase of gradient; the length of time during parking control is shorter on the uphill and the same between on the flat road and on the downhill. In addition, because the algorithm in this paper only uses the torque controlled by the motor to achieve braking and parking, the deceleration is smaller when the vehicle speed is lower than 2km/h, and it is difficult for the driver to implement accurate braking distance requirements.

3. The vehicle test results and evaluation method

3.1. The evaluation of drivability

Drivability is a representation of the performance related to vehicle driving, which generally includes dynamic performance and handling stability. The drivability in this paper only aims at the performance of acceleration response accelerator pedal opening in the longitudinal driving direction of the vehicle under the single pedal mode. The single pedal mode provides a new driving habit for the driver, which means driver shall keep the accelerator pedal opening when driving, and how to evaluate the driving habit is a new topic. For the evaluation of drivability, at present many OEMs implement the evaluation through subjective evaluation based on experience, and some testing technology consulting companies provide objective evaluation services, such as AVL developed DRIVE system as an objective evaluation tool. In order to evaluate the performance of single-pedal function in a real vehicle objectively, the following evaluation methods and indexes are formulated for pure electric vehicle;

1) On the road without slope, with SOC 100% as the initial condition, drive to 120km/h, release the accelerator pedal and slow down to park, then stop the test until SOC is less than 80%;

2) On the road with different slope, drive to 20km/h with SOC 20%~80% as the initial condition, release the accelerator pedal and slow down to park, then stop the test until vehicle can't stop at this slope.

Among them, the main evaluation indexes for the single pedal under the flat road conditions are the maximum braking deceleration, the maximum braking deceleration response time and the maximum SOC of single pedal braking; for the test under the slope road conditions, the main evaluation indexes
are the maximum braking parking gradient and the maximum gradient parking slip distance. The evaluation standards about each evaluation index are shown in the table below. In research the final evaluation scores of electric vehicle is 89.

3.2. The vehicle test results

Figure 11. The vehicle test result on 5%slop road

Figure 12. The vehicle test result on flat road

Figure 13. The vehicle test result on -5%slop road
### Table 2. Evaluation criterion

| Index                  | Unit criterion | criterion |
|------------------------|----------------|-----------|
| Max deceleration       | score          | 0  60  100 60 0 |
|                        | m/s²           | 0 1 2 3 4 |
| Max deceleration       | score          | 100 100 100 60 0 |
| response time          | s              | 0.1 0.2 0.3 0.5 1 |
| Max SOC                | score          | 0 60 100 |
|                        | %              | 90 95 100 |
| Max hold slope         | score          | 100 100 100 60 0 |
|                        | %              | 29 20 12 8 5 |
| Max rolling distance   | score          | 100 100 100 60 0 |
|                        | m              | 0 5 10 20 30 |

Considering that the parking control algorithm is more complex in single-pedal function, the single-pedal parking is tested in an electric vehicle. From the actual test results from Figure 11-13, it can be seen that the electric vehicle can realize single pedal parking on flat road, uphill and downhill road. Based on all the evaluation indexes, the final score of real vehicle about single-pedal function is 89 points.

### 4. Conclusion

In this paper, the control algorithm and evaluation method for the development of single-pedal function of electric vehicle are studied. The traditional position PID control algorithm is applied to realize the launch, acceleration, braking and parking in single-pedal function. Based on the test results of an electric vehicle, the objective evaluation indexes are established to give the evaluation results. It needs to be pointed out that the single-pedal function is applicable to new energy vehicles such as pure electric vehicles. The single-pedal feature can be realized only by controlling the motor torque during driving, and the difficulty lies in the parking control. The research in this paper realizes the parking function through the motor torque only, and the disadvantage is that the parking deceleration at low speed is small, which cannot guarantee the precise parking distance demand of driver, so the following research needs the coordination with the braking system such as ESP to optimise the parking control.

### References

[1] Wei Liu, Hongzhong Qi, Xintian Liu, Yansong Wang, Evaluation of regenerative braking based on single-pedal control for electric vehicles. Frontiers of Mechanical Engineering 15,166-179(2020)

[2] Qiu C K, Wang G L. New evaluation methodology of regenerative braking contribution to energy efficiency improvement of electric vehicles. Energy Conversion and Management, 2016, 119: 389–398

[3] C. Lin, X. Liu, A. Dong, A Research on Regenerative Braking Control Strategy Based on Acceleration Pedal Travel. Automotive Engineering, 2015-07

[4] Gou Jinfang, Wang Lifang, Liao Chenglin, The coordinated control of motor regenerative braking torques defined by accelerator pedal and brake pedal of electric vehicle. IEEE Vehicle Power & Propulsion Conference, 2012/10/01