Evaluation of Parking Collision Avoidance System with Integrated Electric Parking Brake

Chi-Chun Yao*, Jiun-Jie Chen², Liang-Cheng Chang², Shih-Chieh Huang²

1. Automotive Research & Testing Center, Taiwan
2. Automotive Research & Testing Center, Taiwan
No.6, Lugong S. 7th Rd., Lukang Township, Changhua County 50544, Taiwan (R.O.C.)
E-mail: chichun_yao@artc.org.tw
Telephone:+886 47811222 ext:2357

Abstract

With the increasing requirement on vehicle rear safety of advanced driver assistance system, the purpose of this research is to develop a parking collision avoidance system using Integrated Electric Parking Brake (IEPB) technique, which includes collision-avoidance algorithm, performance evaluation of brake and sensing, system motor fault diagnosis, and system validation. Our proposed system uses common ultrasonic sensors to detect rear obstacles, and the electric parking brake is applied for brake actuator. In order to establish a more complete system function, a motor diagnosis mechanism will be designed and added in ECU to detect the system failure while executing the braking. The final experimental results indicated that the system can execute the approximate 0.2G deceleration properly for preventing collision in the parking status if the driver is distracted, and the six kinds of system statuses also can be estimated effectively.

KEYWORDS:
Parking Collision Avoidance System, Electric Parking Brake, Parking Safety

Introduction

Due to the development of automotive electronics, more and more vehicle systems apply the electronic technology to implement the intelligent function for providing convenience, comfort, and safety in driving, especially in advanced driver assist system (ADAS). Compared with traditional passive safety, the active safety system can predict even prevent the accidents happening, such as Autonomous Emergency Braking (AEB), Adaptive Cruise Control (ACC), Lane Keeping Assist (LKA), etc. Since European New Car Assessment Programme (Euro
Evaluation of Parking Collision Avoidance System with Integrated Electric Parking Brake

NCAP) adds the active safety items to vehicle ranking, international vehicle manufacturers also started to focus on this area and announced many relative front active safety technologies in recent years.

In the vehicle rear safety field, the ultrasonic or camera sensors are still mainly used for parking warning system. In the parking status, the driver must continue to pay attention of the rear environment to avoid collision. Once the driver is distracted, the vehicle accident could happen. The traffic report (2014/03/31) of National Highway Traffic Safety Administration indicated that in these parking accidents the children under 5 years old accounted for 31%, and this is because the children’s bodies are short and inconspicuous.

Therefore, the paper proposes an implementation of parking collision avoidance system, including collision avoidance algorithm, system motor diagnosis, vehicle sensing estimation, the performance test of brake, and system validation. In addition to general warning messages, the system will provide the active brake assist to stop the vehicle when the collision is predicted to happen in a short time. The function of active brake is executed by integrated electric parking brake module which has become the standard equipment in many vehicles. In contrast with the expensive brake-by-wire system, both the development schedule and the cost of sales are acceptable by vehicle suppliers. Besides, this paper will also evaluate feasibility of parking collision avoidance technology using ultrasonic sensing and electric parking brake actuator because the original purpose of IEPB is not for general braking.

System Structure

The full system structure is shown in Figure 1, and it is known clearly that the key components include the electric parking brake (EPB), ultrasonic sensors, and electronic control unit (ECU).

![Figure 1 – System Structure](image)

The main purpose of electric parking brake is to replace the traditional parking brake by the configuration of motor and relative mechanism, and the advantage is that the driver only needs a switch to execute the parking or release brake simply. With the electric control method and vehicle network, EPB system can own more intelligent function such as “Auto
Park”, ”Take off Assistant” and “Dynamic braking”, and it decreases the vehicle damage from driver’s carelessness. There have been lots of vehicles equipped EPB systems in the market, which can be separated in two types: Cable Electric Parking Brake (CEPB) and Integrated Electric Parking Brake (IEPB). CEPB system uses the cable to deliver the brake force to the brake system, and IEPB overall system is equipped directly in the brake caliper of rear wheels. Therefore, IEPB will have a faster response time in enabling the brake, which means the brake actuator can finish the brake action in the shorter time than CEPB, and this is also the reason our parking collision avoidance system chooses IEPB technology.

About the sensing unit, ultrasonic sensors can generate the high frequency sound wave and obtain the distance information by the time between sending and receiving. In this paper, we will use two ultrasonic sensors to install in the rear of host vehicle, and the detection distance is up to 0.8 meters.

The electronic control unit is the core of parking collision avoidance system, and it is used to receive the sensing or vehicle network information and control the brake actuator properly. ECU does not only contain the original IEPB intelligent and safe mechanism, but also will add the TTC (Time-To-Collision) algorithm for the purpose of parking safety.

By the integration of above components, if the vehicle is too close to obstacles during the period of parking, the system will depend on the different dangerous levels to provide a warning message or the brake assist for reducing the accident rates effectively.

**Parking Collision Avoidance System Design**

Due to the fact that the main function of this system is to predict if the collision happens and send a brake command to stop the host vehicle by detecting the rear obstacles, the performance of obstacle sensing and brake actuator will become quite critical. The relative estimation will be also discussed as the following content.

**Collision Avoidance Algorithm**

This system uses Time-To-Collision method as the control method [1], and TTC means the collision time of obstacles and the host vehicle. The equation is shown below:

\[
TTC = \frac{s}{V_0} \quad (1)
\]

where TTC is the collision time; s is the distance between the obstacles and the host vehicle measured by ultrasonic sensor; \(V_0\) is the vehicle speed.

Rusolf [2] depicts that the driver needs 0.69 second to move their foot from the throttle pedal to brake pedal. Consequently, if the driver is distracted or does not pay the attention during the period of parking, the TTC has to be defined less than 0.69 second on the premise that there cannot be the collision after executing the brake assist.
System Motor Fault Diagnosis

Due to the fact that the proposed system applied IEPB technology for brake actuator, the IEPB motor status diagnosis will become an important issue. In general, the additional encoder will be needed to install in the motor for determining the system status, but the cost is expensive, especially in automotive field. Therefore, we will design a fault diagnosis method by the motor current characteristic in the operation to detect the motor present status.

The DC motor armature current can be separated in two parts: DC current (iDC) and AC current (iAC), and the latter is relative to the motor current ripple variation. By the motor voltage and current formula, the relationship between the pulse of ripple current and rotating speed [3] is represented in Equation 2.

\[ f = \frac{lcm(2p,k) \times n}{60} \]  

(2)

where \( f \) is the frequency of current ripple (Hz); \( n \) is the motor rpm; lcm is the least common multiple; \( p \) is the number of pole; \( k \) is the number of commutator segment.

While the motor we use in this paper operates for one rotation, the number of pulse in the current ripple will be ten (\( k=5 \) and \( p=1 \)). In other words, after the full current ripple is recorded by the ECU controller, the system can obtain the position and speed of motor and detect if the motor operates in a correct status.

And then the DC current (iDC) have to be analyzed to set up an effective diagnosis method. For low-frequency dc current, the full current variation from IEPB lock to release is comprised of 3 phases:

- \( i_{\text{start}} \rightarrow i_{\text{v1}} \) : the inrush current from the motor static status to the dynamic status
- \( i_{\text{v1}} \rightarrow i_{\text{v2}} \) : the current variation from moving brake piston to disc
- \( i_{\text{v2}} \rightarrow i_{\text{end}} \) : the current variation from tight brake disc contact

Figure 2 shows the full DC current variation.

![IEPB Current Variation](image)

**Figure 2 – IEPB Current Variation**

For the force control, \( i_{\text{end}} \) current can be used to determine if the motor operates, and the system can also decide if the full mechanism gets jammed or loose by the time from \( i_{\text{start}} \) to \( i_{\text{end}} \). If the time \((a+b+c)\) is less than the set time, the phenomenon is caused by the jammed mechanism. On the contrary, when the time is larger than the set one, the motor has already
got loose. Combine this DC current variation when IEPB starts with AC characteristic, the system motor diagnosis method is designed as Figure 3.

![Figure 3 – System Motor Diagnosis Flow](image)

where $I_{DC}$ is the DC current; $I_{DC,\text{set}}$ is the current set value of IEPB maximum brake force; $T$ is the IEPB lock operating time; $t_{\text{set}}$ is IEPB normal operating time ; $N$ is the estimated value of current ripple; $N_{\text{set}}$ is the normal value of current ripple, which is within a range.

**Integrated Electric Parking Brake Performance**

In this paper, Luxgen SUV type is used for the experimental vehicle which is equipped IEPB system we designed before. Firstly, the vehicle weight needs to be measured as Table 1, and the result is 1813kg.

**Table 1: Vehicle Weight**

<table>
<thead>
<tr>
<th>Weight(kg)</th>
<th>Weight(kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front/Left Wheel</td>
<td>542</td>
</tr>
<tr>
<td>Rear/Left Wheel</td>
<td>380</td>
</tr>
<tr>
<td>Front/Right Wheel</td>
<td>527</td>
</tr>
<tr>
<td>Rear/Right Wheel</td>
<td>364</td>
</tr>
<tr>
<td>Total Weight</td>
<td>1,813(kg)</td>
</tr>
</tbody>
</table>

The second one is to evaluate the braking force provided by IEPB system. The testing platform is established and shown as Figure 4.

![Figure 4 – Testing Platform of IEPB System](image)

The testing platform of IEPB system includes the rear axle, the actuator (IEPB module), the load cell, the data recorder, ECU and power supply. The rear axle, the brake disc and brake caliper is comprised of the full platform; the actuator is the IEPB module; the load cell is a kind of force-sense component measuring the force from the piston to brake disc; the data
recorder is used to recode the relation of input current, output brake force and time variation; ECU controls the IEPB logic action.

By the experimental platform, the result is shown as Figure 5. The blue dotted line represents the current while IEPB brake is active, and the red line is the normal force between the brake lining to brake disc, which is measured through the load cell of the testing platform. This system uses the current values as the force control feedback signal during the process of locking. When the IEPB current is set to 8A, the normal force that the actuator outputs to the lining will be 750kg, which is also the braking force provided by IEPB. Due to the fact that the actuator is installed on the vehicle rear wheels, IEPB system will make the lining contact with this brake disc to bring the friction for brake effect, and Figure 6 depicts that the relation of the brake disc and the ground force.

![Figure 5 – Brake Force Provided by IEPB Module](image1)

![Figure 6 – The Force Diagram](image2)

where F is the friction between the ground and tire; D is the distance between the contact point of the ideal tire on ground and the center of the tire; D’ is the distance between the contact point of the actual tire on ground and the center of the tire due to the deformation effect; f is the friction between the lining and brake disc.; d is the distance between the center of lining to the center of tire and equal to 14.5 cm.

The tire specification of our experimental vehicle is 235/55/R18, so D’ will be 33.2cm while the actual tire pressure is 35lb/in2.According to the reference [4], the present lining belongs to “H” type, and the friction coefficient is usually larger than 0.55. Therefore, the friction force between the lining and brake disc can be estimated as 412.5kg in the most series condition (friction coefficient=0.55). By Equation 3, F can be calculated out as 180.2kg.
Evaluation of Parking Collision Avoidance System with Integrated Electric Parking Brake

\[ f \times d = F \times D \]  

(3)

And then, the deceleration provided by IEPB will be obtained as 0.2G by F value and the vehicle weight while executing the braking action. Figure 7 shows the actual condition about IEPB module installed on the vehicle.

Figure 7 – IEPB System Installed in Vehicle

In the next step, the actual braking distance of the system will be measured in the different velocity, and meantime the results are also compared with the estimated braking performance from the vehicle weight and IEPB braking force calculation. Figure 8 indicated the braking distance at different speed.

Figure 8 – Braking Distance

From Figure 8, it can be seen that the braking distance is 0.69m when the vehicle speed remains 6 km/hr. If the system applies a ultrasonic sensor which can detect to 80cm distance, the max proper speed will be 6.4 km/hr; otherwise there could be a collision happening.

Figure 9 – Braking Situation in the Parking Status
Evaluation of Parking Collision Avoidance System with Integrated Electric Parking Brake

Figure 9 shows the data that the vehicle speeds up from 0 to 6 km/hr, and then the system executes the brake action. These curves represent the moving distance, speed and acceleration separately; the moving distance is from the speed integral; the speed is from the acceleration integral; the acceleration is measured by the RACELOGIC VBOX high accurate GPS-based equipment. From the results, the max deceleration appears at 12s and the first deceleration starts at 11.2s. The vehicle is stopped at 12.7s, so the braking distance can be calculated by the integral of acceleration from 11.2s to 12.7s.

**Ultrasonic Sensor Performance**

In this section, it will be described that how to confirm the beam pattern and performance of the ultrasonic sensors. Firstly, the testing field is needed to be set up. The environment has about 400 cm length and 250 cm width with 10cm*10cm grid, and an ISO 17386 standard object are used as obstacles. Figure 10 and 11 show the testing situation.

![Figure 10 – Testing Condition about Ultrasonic Sensors](image)

![Figure 11 – Beam Pattern of Ultrasonic Sensor](image)

According to the result (Figure 11), the farthest of detecting distance is about 80cm, and the nearest one is 20cm. In other words, the braking distance generated by IEPB cannot exceed this distance, otherwise the collision would appear. This parameter is also used for the main reference if IEPB system is suitable for parking collision avoidance application.

**System Validation**

The system validation includes two parts: system motor diagnosis validation and collision-avoidance functional test.
Motor Diagnosis Test

By the above-mentioned testing platform, an additional encoder is installed inside the motor for position reference, and the relationship between the encoder and current ripple phenomenon will be confirmed. Figure 12 shows the waveforms of encoder signal and current ripple while the system is operating.

![Encoder Signal](image1)

**Figure 12 – Motor Encoder Signal and Current Ripple.**

From Figure 12, it can be seen that when the motor operates for one rotation (i.e. the encoder signal shows one cycle), the current ripple brings about 10 pulses in this cycle. This experimental result fits the content we mentioned previously, and it will also be used for the motor position estimation.

According to the system diagnosis flow we designed, there are six system statuses needed to determine. By some basic logic and rules, “Loose Actuator”, ”Jammed Actuator”, and “System Error” are easy to be defined, but the other one are needed to be described in detail. Figure 13 depicts that measured conditions in normal, reduced motor efficiency, and abnormal carbon brush.

In the IEPB normal operation, the average number of current ripple pulse is 230, and the value of encoder is 24. Due to the current error produced from the start to the end, the maximum error is approximate 7% in ten tests.

It is also known clearly that when the efficiency of the system decreases (IEPB locks twice), the brake force and the pulse of current ripple reduce apparently because of lower motor EMF and the amplitude of current ripple. At the same time, the ratio of the motor rotation and the ripple pulse will be lower than 1:10.

![Graph](image2)

**Figure 13 – Relationship between Current Ripple and Force.**
Evaluation of Parking Collision Avoidance System with Integrated Electric Parking Brake

For the condition of abnormal motor brush, the result shows the lower brake force than the normal, but the pulse of current ripple increases to 339. When the motor brush is worn down seriously, the high-frequency current will focus on one loop during the phase-change process. Although the motor EMF increases during the rotation, the system brake force still is lower than the normal one because of unbalanced motor operation.

Collision-Avoidance Function Test

In the collision-avoidance system test, the full function is installed on the vehicle and validated. Once this system detects obstacles, the IEPB module will enable the brake immediately to confirm the correctness of above-mentioned estimation. Compare the results from the system integration test with that from IEPB braking test, Figure 14 shows the comparison of the braking distance.

![Figure 14 – Braking Distance of Proposed System](image)

In Figure 14, the red solid line represents the estimated braking distance of IEPB itself and “X” on this line is measurement value; “triangle” on the blue dashed line is the actual value from full system testing. It can be seen clearly that there is an apparent gap in the actual braking distance. The pre-estimated max suitable speed decreased from 6.4 km/hr to 4.6 km/hr. The reason should be about the time delay from ultrasonic sensing and the other control unit. Furthermore, the time delay generated by electric control unit can be neglected because the ultrasonic unit needs more time to send distance information. Another reason is relative to the ultrasonic sensor design, which applies polling method to sending the detecting distance. After all of sensors finish the detecting action, the distance information is just passed out via CANBUS. That delay time is measured as about 0.3s. Equation 4 is the new formula for adding a time-delay factor.

\[ s = \frac{V_0^2}{2a} + V_0 \times t_{\text{delay}} \]  

\[ (4) \]

where \( t_{\text{delay}} \) is the system delay time generated by ultrasonic sensing.

By Equation 4, the braking performance curve of parking collision avoidance system can be estimated as the blue dashed line in Figure 15. If the vehicle speed is higher, the time-gap
effect will become more obvious. The applied ultrasonic sensor is originally designed for warning in parking, so the response time of detecting is suitable in low speed. Therefore, on the premise that the max suitable speed decreases from 6.3 km/hr to 4.6 km/hr and the collision can not appear, the TTC parameter of this system will be set to 0.63s which is still less the goal value 0.69s.

![Figure 15 – The Relationship between TTC and Braking Performance](image)

In Figure 15, the oblique line based on TTC 0.63s and the curve from the system test intersect at the point of 0.8m and 4.6km/hr, and the acceptable operating area will be under both these lines- oblique line (TTC=0.63s) and horizontal line(0.8m) In order to increase the system application and reduce the driver uncomfortable feeling while enabling the braking in an emergency situation, ECU will adjust different braking time at different speed in this zone. These above testing results can also be as the design reference in the future for the ultrasonic sensing choice or the improvement of response time.

Conclusions

In conclusion, the paper mentioned a parking collision avoidance system implementation based on ultrasonic sensors and IEPB technology. The estimated methods for the braking actuator and sensing performance are also established to evaluate the vehicle rear safety system design. By the analysis of braking, the deceleration provided by the actuator can be measured while the vehicle is backing up for understanding the required braking distance. The detecting area and performance of ultrasonic sensors are verified to determine the max suitable vehicle speed. In addition to the collision-avoidance function, the motor diagnosis is also designed and verified to add the reliability of full system.

Although the single IEPB actuator can approach the collision avoidance mechanism under 6.4 km/hr, the max suitable vehicle speed of the full system is decreased because of time delay 0.3s from ultrasonic sensing. The experimental result indicated the system can still execute the brake assist action effectively for preventing collision in TTC 0.63s, and the suitable vehicle speed is under approximate 5km/hr.
Moreover, for the vehicle rear safety system design in the future, the choice of sensors, detecting area, system response time, and real-time command must be re-considered as the main points besides the braking performance. Once the system applicable speed can add effectively, the practicability and adding value of relative technology will become more comprehensive.

Acknowledgments

The work was supported by Department of Industrial Technology, Ministry of Economic Affairs, Taiwan, R.O.C.(Contract No. 104-EC-17-A-23-0803)

References

2. Rudolf Limpert, “Brake design and safety” Published by SAE International, 2011