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A Research on the Test and Evaluation Method of Autonomous Vehicle Emergency Braking System Based on Typical Test Scenarios

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Abstract

With the emergence of self-driving vehicles, the Autonomous Emergency Braking System (AEB) has become a crucial element in preventing traffic collisions. When comes to public trust and road safety, AEB needs to be really reliable and working well. In this paper, a series of testing and evaluation methods are introduced about AEB system using some typical and key scenarios that reflect the real world driving scenario. Do research starting from having the basic structure for all kind of test scenario like CCR (car-to-car rear stationary), CCRm(car-to-car rear moving), CCRb(car-to-car rear braking), VRU(Vulnerable Road User) and more. The test protocol details, test environment, instruments in vehicle, target, recording data. The fundamental aspect of the evaluation method comprises of 4 KPIs: Collision_avoidance, Speed_reduction_on_impact, Ttc_at_ttc_intervention and Peak_braking_deceleration. In the paper, it takes hypothetical test data on these situations to prove how this works. The results show that AEB performance depends much on the situation, whether it's initial velocity, relative velocity, or target type. That means we should test out different situations to see how far we can push an AEB. The proposed methodology gives automakers, regulatory bodies and research institutions a regular, iterative method to do strong evaluations and comparisons of AE B performance, which is good for making safer AD Ts.

Keywords

Autonomous Emergency Braking (AEB), Test Scenarios, Performance Evaluation, Vehicle Safety, Autonomous Driving, NCAP.

1. Introduction

Autonomous driving technology is progressing at a fast pace, completely transforming the automobile sector, making roads safer, traffic flowing more smoothly, and mobility getting better. The basic idea is that it creates and uses advanced driver-assistance systems (ADAS), and AEB also belongs to the category of active safety[1]. The AEB system was for automatic detection of the possibility of a frontal collision with cars, pedestrians, bicycles, similar things, and so on, and automatic application of brakes without the driver having to do so[2]. They can save lives and reduce injuries according to the worldwide international safety organization, NCAP is gradually more and more common[3]. but still the efficiency of operation of an AEB system doesn't hit 99% as it is a function of the interaction between perception elements of AEB like a camera, radar, LiDAR, the decisions taken and the current traffic state[4]. so we need to create a good evaluation method so that the self-driving car can be safe and trustworthy. How to build up an evaluation system that can show many different and surprising situations as real traffic accidents are, that is a problem[5]. It works well under a good system but only a very easy system like a simple sunny-weather and flat road, it fails like a haze-target, weather and higher-speed target[6]. This paper overcomes this shortcoming with a structure of testing and examination that is designed according to some usual testing conditions which have been

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found out from analyzing the present accident data and the internationally accepted safety standards[7]. Establish a commonly accepted way to measure how well a car's AEB works so that people can easily compare a car's AEB made by different companies and also encourage other car models to make AEB as good as possible in the future[8].

2. Selection and Definition of Common Testing Examples

To conduct proper AEB evaluation, the test scene have to be representative of ordinary cases and also to be the extreme case of one of any AEB systems in order to understand the functional envelop of which. (a) Randomly choosing scenarios[9]. It may feel one feels a system can do much more than they really do. Thus, this research takes an organized approach using data from many accidentology reports, standardization work used by organizations like Euro NCAP, and the C-NCAP program in China. I. Based on number of precrashevents I chose scenarios to analyze different parts of theAEBsystem[10]. The research consist of 4 main scenarios. The first is Car-to-Car Rear Stationary: We get close to a parked car, which often happens on busy roads as illustrated in the picture: This is a very basic test just to check on a system detection and to see if I can activate the brake at different speeds. the second scenario is CCRm where the car gets closer to another car that is moving slower than it but constant with respect to the other cars. This scenario has two: an accurate relative velocity and whether it doesn't matter if the closed speed is high or low. The third test is CCRb, there's a car ahead of you, and it suddenly puts on the brakes, so this tests how quickly does the AEB see danger in front of you? What does it do and how fast? And lastly, the ones to check safety for and safety for non motorist will be case for a pedestrian walking out oncoming the field of vision of the car behind an obstacle. This is a VRU case. In Scenario 2 we have a more complicated scenario were we need the perception to find a half hidden target that changes its direction randomly. And the control has to run an instant, rapid, and potent emergency brake. The four scenarios are part of a set, and together they assess the capability of an AEB systems' main capability with relation to the mentioned predictable, dynamic, and complex threat scenario. and it would've been a pretty good foundation for a more big picture of the whole system performance.

3. Test Method, Evaluation Indicators

To create a reliable and repeatable test evaluation for an AEB System, we must create a testing protocol and also know what is good. The experimental arrangement is doing the study in a controlled place like a track that's recognized for real information. Testing is performed in a vehicle commonly known as a Vehicle Under Test (VUT) equipped with a certain AEB. The state variables like velocity, acceleration and yaw rate are correctly followed up by the DGPS and IMU that sample 100 samples or more per second. Often, a standard foam and vinyl surrogate, referred to as a Global Vehicle Target (GVT), is utilised since it looks like a car and reflects it so that it does not cause damage. Regarding the VRU test, the person is either a pedestrian or a cyclist dummy. There are robots platforms that these can be made to move accurately and reliably. The whole test make sure that the VUT reach the destination by certain route and certain speed plan. The allowed errors will basically stay on plus or minus 1.0km/h. System performance calculation will use 4kpis. Number 1 is collision avoidance which will mark as 0 or 1 if there is any impact. we can't avoid the crash anymore, Speed Reduction upon Impact has to be an important metric as well, lower speed means less injury. 3 Time To Collision @ Intervantion(TTC @ Intervantion)=Kp that shows the remaining time to which a collision might occur from the moment the first Autonomous Brake command of the AEB System is issued This metric provides information about the threshold for calculating danger and making decisions inside the system. finally, Peak Braking Decel. is the magnitude of the brake as de- tailed in g and gives info on the consideration for the sys- tem contols and the smoothness felt by the

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passenger People who like these very strict ways make sure the things they find out are never wrong and each time they make decisions, it’s fair when compared with all other systems and exams

4. Results and Analysis

The representative AEB system for each of the four cases is confirmed by performing a set of tests according to the established method. The result has been collected and put into the following table, there is one table for each test condition The given data gives a description of “normal” AEB performance, The next part is analyzing each result in the tables, putting the number into perspective to performance evaluation The different dynamic parameter difference in terms of the effectiveness of the system shows the possibility of multi-scenario evaluation method used in this paper.

Table 1. AEB Performance in Car-to-Car Rear Stationary (CCRs) Scenario

Test Run	Initial VUT Speed (km/h)	Collision Avoided (Yes/No)	Impact Speed (km/h)	Peak Deceleration (g)
1	20	Yes	0	0.85
2	30	Yes	0	0.92
3	40	Yes	0	0.98
4	50	No	12.5	1.05
5	60	No	25.3	1.06

The CCRs scenario results as seen in table 1 show distinct performance thresholds based on the initial speed of the test vehicles for the AEB systems. System fully avoided collisions under 40kph. And system stopped completely at progressively increasing peak decelerative forces with initial speed being progressively faster. This is to say that it is the most basic recognition for a static object and the application of emergency braking at less troublesome conditions. But after reaching an initial speed of 50KM/H it couldn't avoid a collision anymore, however it drastically slowed down its speed. The collision speed is 12.5km/h when the start speed is 50km/h, and the collision speed is 25.3km/h when the start speed is 60km/h. This means the collision severity has been greatly reduced. the highest values for deceleration are around 1.05g which means that the system has reached the physical limitations of braking performance which is set by the limits of tire road adhesion and also brake system capacity. It mentions physical limitations that even great software won’t overcome and stresses that testing ought to run over various speeds so as to spot what the system does when pushed against limits.

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Table 2. AEB Performance in Car-to-Car Rear Moving (CCRm) Scenario (Target Speed: 20 km/h)

Test Run	Initial VUT Speed (km/h)	Relative Speed (km/h)	Collision Avoided (Yes/No)	Impact Speed (km/h)	TTC at Intervention (s)
6	40	20	Yes	N/A	2.8
7	50	30	Yes	N/A	2.5
8	60	40	Yes	N/A	2.1
9	70	50	No	28.1	1.8
10	80	60	No	42.4	1.6

Performance for AEB system is checked by using a CCRm scenario that includes a lead vehicle which is traveling slower, as shown in Table 2. It can avoid the collision if the relative speed is less than 40km/h (VUT = 60km / h, target = 20km / h). On the direction of intervention, TT C. Trend is also interesting. The higher the speed, the slower it is, so the system starts braking later after it is successful in escaping, the TCC decreases from 2.8 seconds to 2.1 seconds. maybe that means there is something to keep the car from making a mistake by warning if it's not really dangerous, like when cars are just following one another. The system only helps when it sure it will crash when closing faster but there are limits to this At a speed of 50km/h, the intervention starts 1.8 seconds after the TTC becomes zero, which is too late to avoid a collision, resulting in a collision at 28.1km/h. When the relative speed hit 60km/h, the performance dropped. It can test the system's decision-making logic for non-zero relative velocity with sustained, continuous movement, which is a more complex perception problem than deciding if there is a stationary object.

Table 3. AEB Performance in Car-to-Car Rear Braking (CCRb) Scenario (Lead Vehicle Deceleration: 0.5g)

Test Run	Initial VUT Speed (km/h)	Initial Headway (s)	Collision Avoided (Yes/No)	Speed Reduction (km/h)	Peak Deceleration (g)
11	50	1.2	No	28.2	1.10
12	50	1.6	Yes	50.0	1.08
13	70	1.6	No	35.5	1.12
14	70	2.0	Yes	70.0	1.11
15	70	2.4	Yes	70.0	1.05

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For the Car-to-car rear brake (CCRb) Tests of table 3, it's necessary to determine the speed at which the entire system reacts to the dynamic threat. The principal variable here is the starting time headway between the VUT and the front car. As the leader goes from coasting into a 0.5g deceleration for a brake, all the AEB can rely on to keep it from hitting anything is that first buffer. If at a speed of 50km/h, the delay time is 1.2sec, then it will crash. But when it comes to 1.6 second for the headway, there is enough room and time for the system to act on it, and to make the VUT stop completely. It is also so at the higher speed of 70km/h. We should make headway at least 2.0seconds. And, the system's reaction, combined with the car's real brakes means there's a shortest safe "end-to-end" distance that depends on how fast you go. These tests are important to know how the AEB system works when cars drive around each other, it's also great to teach about driving and leaving space ahead, even in fancy new cars that have special safety stuff.

Table 4. AEB Performance in Vulnerable Road User (VRU) Scenario (Pedestrian Crossing, 50% Obstructed)

Test Run	Initial VUT Speed (km/h)	Pedestrian Speed (km/h)	Collision Avoided (Yes/No)	Impact Speed (km/h)	TTC at Intervention (s)
16	20	5	Yes	0	1.5
17	30	5	Yes	0	1.3
18	40	5	No	15.8	1.1
19	40	8	No	22.4	1.0
20	50	5	No	28.9	1.0

As shown in the following table, vulnerable road user (VRU) scenario is one of the most challenging scenarios for an AEB system. The test has a pedestrian walking away from a parked car, occluding 50% of the approach. System performance is very different from the vehicle. Collision avoidance success only for low speeds (20, 30): At 40km/h, the speed where the system could easily avoid a stationary car, another pedestrian can't be avoided by the system. it shows you how hard it is for the thing that watches to see things that are really small and not metal, and some parts that you can't easily see. It can be seen that since the TTC at intervention values for scenarios is shorter than CCRm scenario then this means that the system was making decisions later and the most likely cause for the delay could have been because we are increasing the pedestrains speed to 8kms instead of 5kms from the same VUT speed of 40kms which is causing a huge impact speed and therefore proving the system sensitivity towards the targets lateral velocity. These results reveal a necessity for ongoing development in the realm of sensor fusion and prediction algorithms to more effectively contend with the complexities of safeguarding vulnerable road users in densely packed urban areas.

5. Discussion

The outcome of the over all capacity and restrictions of the AEB is based on four different testing situations. It can be seen from the analysis that it is impossible to have any sort of complete judgment on the basis of a single performance index or a single test instance The

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system performed well on the plain ones but got a big drop in performance for the dynamic one CCRb and a perception required when there is an occluded VRU. Because it has different demands on the performance of individual core AEB components. The CRRS test is designed to test the system's maximum braking strength and basic sensor range, but the CCRM and CCRB tests involve how complex the algorithm design is – it must be able to do some calculation of the relatively speed, and predict where things will go in the future, and then decide when to jump in. On the other side of the equation, VRU test drives are looking at whether perception systems can do it. Pedestrians have less area to be seen on radar, and what they do isn't easy to guess, particularly when they are partly covered up, so there is a lot to sort out about finding them, seeing which ones are who, and going after them, making it hard to do the right thing to fix problems fast. like we talked about the limits, like not preventing crashes when running CCR>40km/h, and 1.6sec headway in 70kmh CCRb testing. These boundaries aren't yes/no data points. They are quantitative description of the OOD in which other systems can be directly compared with the performance to this system or they can serve as a base for further iterations of system. The limitation to the current project is that the testing of the project can only happen in controlled test environments such as Clear Sky, Day Time and Pavement. Future work could try out this method on other variable matrices with other weather conditions (i.e., RAIN, FOG) and light conditions (i.e., DUSK, NIGHT), with more complex variables (i.e., TURNING ON INTER, DETECTING CYCLIST W/THROUGH).

6. Conclusion

This paper provides, as a supply, an entirely organized way, or framework, of assessing and measuring autonomous emergency braking systems using a set of predefined test scenarios. We will see how the AEB is doing in the whole system based on looking at the AEB in terms of how it can move and slow down with our CCRm and CCRb, which we have talked about before. We can also see it in terms of a bit more of a dangerous situation where we have the CRRV scenario. Using different Key Performance Indicators like Collision avoidance and speed reduction,the value of time of arrival (TTC)at the intervention as well as the peak deceleration that we can have a better understanding than passing or failing criteria. And it shows us inside the systems perception,decision making and control logic. Analyzing the test results show the need to have tons of tests for lots of different things going on around a plane because the system worked really differently depending on how the planes were interacting with each other when they met. So it seems like even the modern AEB technology can work at preventing harm, but there are limits to how well they can prevent harm too, and that's something we want to know about. This suggested method would provide a standard way to make things just like people who run rules, build things, and buy cars can see what AEB does and then move technology along to help driving on the road stay safer as all the cars get more automated. AEB how it is gonna go in the future for sure more and more complex and more and more varied scenarios and simulated environment to safely test out the system on an infinite variety of real-driving scenarios.

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