2022 7th International Conference on Intelligent Computing and Signal Processing (ICSP)

An Analysis of the Brake Performance of Radar-based Adaptive Cruise Control During Ramp Merging on Simulation Software

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2022 7th International Conference on Intelligent Computing and Signal Processing (ICSP) | 978-1-6654-7857-1/22/$31.00 ©2022 IEEE | DOI: 10.1109/ICSP54964.2022.9778514

***Abstract*—Adaptive Cruise Control System (ACC) is an essential ADAS system for the autonomous vehicle for preventing all kinds of collision in the complex traffic and road situations. Ramp merging has been considered as one of the special traffic situations that can be used for testing the performance of ACC and sensor fusion requirements. To realise the project outcomes, the parametres of Long-Range Radar and Short-Range Radar has been implemented onto the IPG CarMaker with several scenarios of ramp merging been generated for simulating the ACC performance under different sensors and sensor fusion strategies. According to the simulation result, the stability of ACC performance under ramp merging needs to be permitted through adding sensor fusion between Long and Short Range Radar in order to prevent all kinds of collision between different dynamic models of ego and front target vehicle.**

Keywords-radar; adaptive cruise control; ramp merging; simulation software

I. INTRODUCTION

Ramp merging is common traffic situation on freeways, highways and viaducts which including situation of vehicles meet together [1]. The Adaptive Cruise Control (ACC) is a crucial function for the autonomous vehicle when driving in the ramp merging traffic situation as ACC measures the relative speed and distance between the ego and front vehicle [2]. In different mixed traffic situations with different dependencies (e.g road legislation, road situation, vehicle autonomy and sensor detectability), the performance of ACC is not going to be identical. By applying sensor fusion of radars with different detection performance and uses, a radar-based ACC system can be realised and solve the problems of detecting the front vehicle in ramp merging and avoid crashing in emergency situations. Carmaker is a proposed platform which creates 3D virtual environment to accurate vehicle dynamics, sensor performance and environmental configuration [3]. In this article, IPG CarMaker has been used to simulate the ACC performance under vehicle dynamics model, sensor model and environment model.

ACC has been tested with positive influence on the on-ramp mix traffic situations. The main lain vehicle react to the on-ramp vehicle is tested to be positive.[4]. As early as 2010, ACC has been realised and improved on detecting the preceding vehicle by radar in the situation of cornering. With consideration for the vehicle’s slip angle and different front distances, the ACC has been tested with high stability in that situation through proposed identification logic and path estimation logic [5]. Based on the above research, ACC with radar is able to detect the vehicle which is not in the front position when cornering and this consideration is also appropriate to the ramp merging test.

From this study, IPG CarMaker was used to simulate the braking performance of the ACC system when merging into a vehicle on a side ramp. The following chapters of this paper address:

Section II i describes the setup in Carmaker's experiment, including the description of scenarios and vehicles. Section III presents the results of the experiment and analyzes these results. Section IV draws conclusions and presents the limitation of the experiment.

II. EXPERIMENT DESCRIPTION

A. Apparatus

In this article, two ramp insertion experiments are discussed in two different scenarios in the same environment. Both Short-Range Radar (SRR) and Long-Range Radar (LRR) as well as sensor fusion are evaluated under both scenarios.

The experiment presented in this paper is based primarily on a simulation of the software Carmaker 9.1.4. Moreover, the operating system was Windows 11 and GeForce RTX 3070 as GPU.

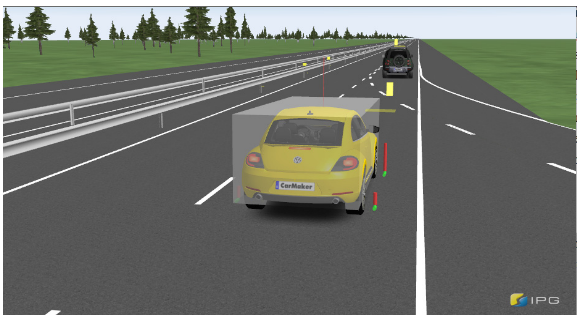

Figure 1. The display of CarMaker's IPGMovie function

The performance of the ego vehicle in the experiment can be observed in the simulation results displayed in CarMaker's IPGMovie function, as shown in Figure 1. The parameter curves are generated by observation of IPGControl.

B. Scenario Setup

Simulation environment with highway under high visibility in the daytime is generated for testing the ACC performance under different sensor implementations (as showed in Figure 1). There are 2 main routes on the driving lane with the ramp merging to the outer lane from the start of the road as showed. The ego vehicle (VW beetle 2012) with different radars implemented are driving start from the Route 0 under autonomous driving. In that case, several scenarios are generated which are using for testing radar and sensor fusion performance through applying a target front vehicle (LandRover Defender110 2020) driving through the on-ramp and cutting in front of the ego vehicle. By controlling the moment of cutting, different braking distances are introduced in order to figure out the sensor limitations in the specific scenario and the improvements generated by the sensor fusion.

Scenario 1

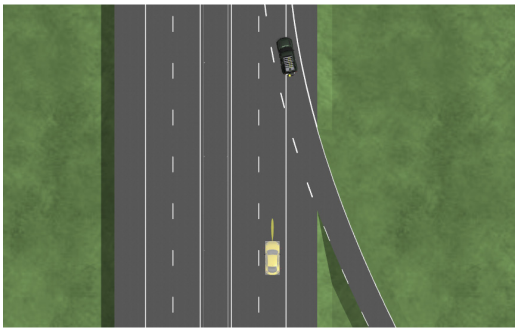

Figure 2. Bird's eye view of Scenario 1

The Scenario 1 is generated for testing the short-range detection performance of ACC. The initial speed of ego vehicle is 100km/h and target vehicle speed of 50km/h. The direct distance between two vehicles at the inserting position was 27m.

Scenario 2

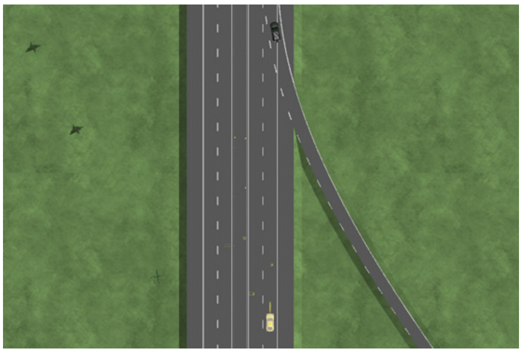

Figure 3. Bird's eye view of Scenario 2

The Scenario 2 is generated for testing the long-range detection performance of ACC. The initial speed of ego vehicle is maintained at 100km/h under automotive driving. This time the target vehicle speed has slowed down to 10km/h when inserting and the direct distance between two vehicles has increased to 100m.

C. Sensor parameter selection

According to the sensor types analysed in [6], there were different properties related to different use cases for Long-Range Radar and Short-Range Radar, as shown in Table 1. The LRR with a detection range from 10m to 250m is suitable for detecting the front vehicle on the same lane due to the narrow horizontal field of view of maximum. The SRR with much shorter detection range from 0.15m to 30m supports detecting the front vehicle which is close to the ego vehicle with the large horizontal field of view of maximum can be used for detecting the target vehicles at lateral position or motion such as ramp merging.

TABLE I. SENSOR PARAMETERS

	Long Range Radar	*Short Range Radar*
Detection Range	10-250m	0.15-30m
Distance Resolution	0.5m	0.1m
Distance Accuracy	0.1m	0.02m
Velocity Resolution	0.6m/s	0.6m/s
Velocity Accuracy	0.1m/s	0.1m/s
Angular Accuracy	0.1°	1°
Horizontal Field of View	±15°	±80°
Vertical Field of View	±5°	±10°
Frequency Band	76-77GHZ	77-81GHZ
Dimensions	74*77*58mm	50*50*20mm

III. PREPARE YOUR PAPER BEFORE STYLING

A. Experiment with Short-Range Radar

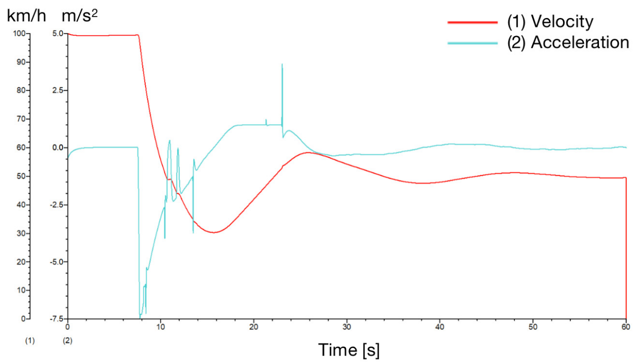

Figure 4. Curves of vehicle with short-range radar in Scenario 1

Under Scenario 1, when the Land Rover car is inserted from the ramp with a distance of about 27 m from the ego vehicle, the ego vehicle begins to slow down at about 7.2 seconds to avoid collision. Then, ego vehicle gradually accelerates after getting out of the collision possibility and finally cruises at a speed close to 50 km/h. The velocity and acceleration curves of the vehicle are shown in Figure 4.

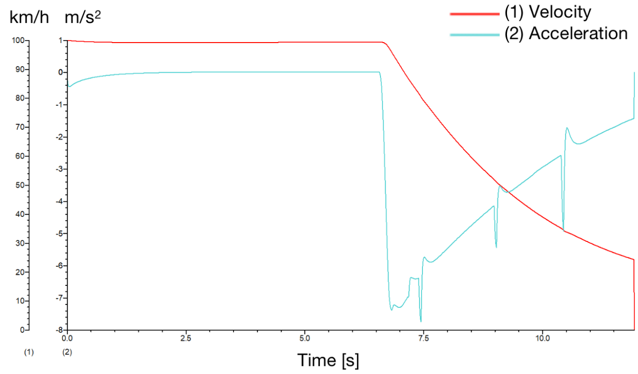

Figure 5. Curves of vehicle with short-range radar in Scenario 2

In Scenario 2, when the vehicle enters at a low speed of 10km / h, the vehicle decelerates in about 6.8 seconds, and the two vehicles collide at a speed of 24.5km/h. As can be seen in Figure 5, the vehicle in this experiment is traveling at a constant speed and accelerating at a constant acceleration.

B. Experiment with Long-Range Radar

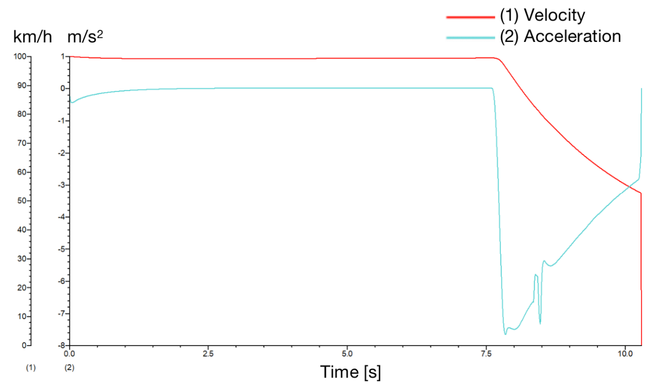

Figure 6. Curves of vehicle with long-range radar in Scenario 1

As a result of the vehicle equipped with long-range radar decelerating around 7.8 seconds into the experiment, and the brakes not being applied in time, there was a collision. Figure 6 shows the vehicle's acceleration and velocity curves

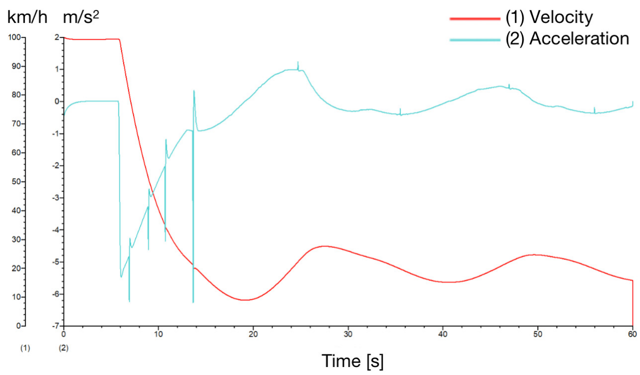

Figure 7. Curves of vehicle with long-range radar in Scenario 2

In spite of the slow speed of the vehicle entering from the ramp, the ACC system of the ego vehicle equipped with a long-range radar enabled it to decelerate around the sixth second and successfully reduce the speed to avoid a collision. The ego vehicle then followed the inserted vehicle and continued to cruise at 20 km/h. Figure 7 illustrates the speed and acceleration curves of the vehicle during the experiment.

C. Experiment with Radar Sensor Fusion

Ego vehicle equipped with both long-range and short-range radars can avoid collisions in both scenarios.

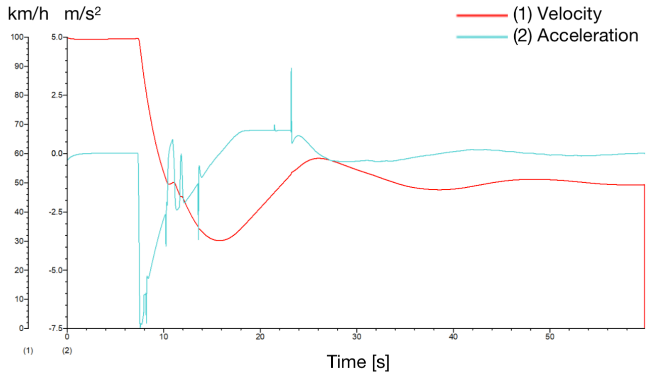

Figure 8. Curves of vehicle with radar sensor fusion in Scenario 1

In Scenario 1, the vehicle braking time based on the fusion of the two radar sensors is close to that of the sensor equipped with short-range radar alone and no collision occurs. The speed and acceleration of the cruising part of the vehicle is relatively smooth, and the speed-acceleration curve of the whole course is shown in Figure 8.

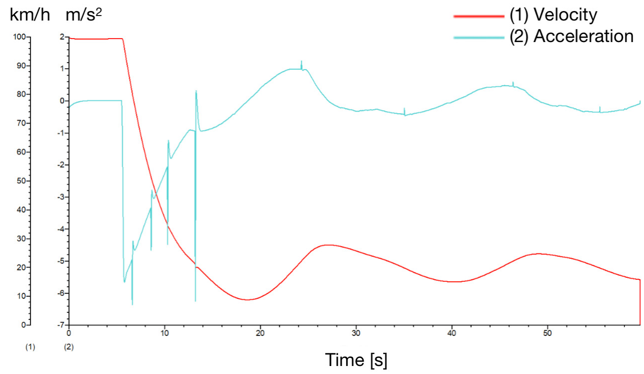

Figure 9. Curves of vehicle with radar sensor fusion in Scenario 2

Additionally, the sensor fusion algorithm in Scenario 2 also produces better results, braking in time without collision, but cruise speeds are not stable. Figure 9 depicts the velocity and acceleration profiles in sixty seconds in this experimental scenario.

D. Analysis

Short range radars have a shorter detection distance, but a wider Field of View, so they perform better at close ranges [7]. However, it is true that long-range radars always have longer detection ranges, but the field of view are narrower[8], and the minimum range always around 0.2 to 10 meter [6], and there are blind spots.

In Scenario 1, the relative speed difference between two cars is not large, but the distance between two cars is greater when the ramp merges. Therefore, the short-range radar with a wider field of view can detect the side vehicle earlier. Due to the greater distance between the two vehicles in Scenario 2, the vehicle equipped with long-range radar can detect the low-speed vehicle in front of it earlier and slow down to avoid a collision.

With the sensor fusion algorithm based on SRR and LRR, it combines the respective characteristics of these two sensors, which improves the performance in extreme situations as well.

IV. CONCLUSION

A. Conclusion

The selection of sensors plays an important role in the advanced driving assistance algorithm. By using SRR, we were able to avoid collisions caused by sudden side insertion, while LRR could assist the vehicle with preemptive braking.

Moreover, sensor fusion provides complementary data and multiple detections. As demonstrated in practical tests, sensor fusion algorithms can provide integrated calculations in extreme situations where a single sensor cannot be controlled adequately. Furthermore, they can also compensate for each other's deficiencies in terms of detection conditions. As an example, short-range radar does not perform well in low-speed obstacle and cannot avoid sudden inserted low-speed vehicle, nor can it avoid sudden insertion collisions. However, by using the LRR and the SRR in combination, these sorts of unanticipated situations can be avoided.

B. Limitations

On the one hand, the tests in this article are mainly based on CarMaker software, and the effectiveness of the experiments greatly depends on the simulation performance of CarMaker, Therefore, to obtain more reliable conclusions, it may be necessary to simulate the same scenario using multiple software packages.

On the other hand, the ego vehicle and forward vehicle selected in this paper are limited to one type of vehicle, and the width and height of the vehicle in front, as well as the sensor installation position of the ego vehicle, will have some influence on the experimental effect.

C. Future Expectation

The advancement of sensor technology has improved the performance of radar sensors, and it is believed that the advancement of technology will allow for the development of adaptive cruise sensors that will take into account both field of view and detection range [9]. In addition, because long-range radar and short-range radar have similar performance, in practical applications, more sensor fusion algorithms are the fusion of vision and radar [10] or the fusion of connection and radar [11]. Thanks to the diversification of the fusion algorithm and hardware upgrade, the ACC system will operate more reliably and safely during on-ramp merging.

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