Contemporary Engineering Sciences, Vol. 7, 2014, no. 22, 1139 - 1145
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http://dx.doi.org/10.12988/ces.2014.49142

Analysis of Forward Collision Warning System Based on Vehicle-mounted Sensors on Roads with an Up-Down Road gradient

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Abstract

Vehicle-mounted sensors have a limited detection range on a road with a gradient in relation to the vehicle infront. This study analyzes the performance on a road with a gradient of a forward collision warning system based on vehicle sensors. The level of warning given in relation to a vehicle infront is defined by the time-to-collision. Simulation results show that the forward collision warning system with vehicle-mounted sensors cannot function properly on a road with a gradient of over 9%. Furthermore, the limit ranges of the vehicle sensors were quantitatively analyzed.

Keywords: Forward collision warning system (FCWS), vehicle-mounted sensor, radar, ADAS.

1 Introduction

Increasing death tolls from vehicle accidents and stricter regulations on vehicle safety have led to extensive research into intelligent automobiles [1, 2]. The representative intelligent system used is the Advanced Driver Assistance System (ADAS), which consists of a parking assistance system, blind-sight detection system, lane departure warning/mitigation system, and a forward collision warning system (FCWS). Recognition sensors are important in relation to such ADAS technology, and the representative ADAS vehicle sensors are ultrasound, radar (radio detection and ranging), lidar (light detection and ranging), and camera [3–5]. Of these, radar is robust to weather conditions and has a high vehicle recognition performance. It is thus widely used in ADAS [6].

A previous study on the performance of vehicle radar analyzed only the radar's performance in relation to distances measured on straight roads for four frequency bands 300MHz, 5.8 GHz, 24GHz, and 47 GHz, using a chirp signal [7]. Another study investigated only the short-range transmission loss characteristics at 24 GHz, which is in the frequency range of vehicle collision mitigation radar [8]. Therefore, the performance of vehicle radar for gradient road conditions requires further investigation, and in this study we therefore investigate the performance of the FCWS based on vehicle radar on ordinary roads with varying gradient road conditions.

2 Performance analysis of FCWS based on vehicle radar

2.1 Performance analysis configuration

This study investigates the performance of the FCWS based on vehicle radar in gradient road conditions, as shown in Fig. 1. Performance analysis requires not only a detailed modeling of the vehicle radar, but also an analytical model of the gradient road conditions. Therefore, PreScan was used to model the Long Range Radar (LRR) and the Short Range Radar (SRR) installed in vehicles, and CarSim was used to reflect the relatively high degree-of-freedom dynamic characteristics of vehicles equipped with these sensors.

The scenario for analyzing the performance limits of vehicle radars is shown in Fig. 2. The host vehicle equipped with radars moves from its initial position (at 0 m) at a constant speed of 50 km/h. The target vehicle is set to stop at positions 1, 2, and 3 on the gradient road, as shown in Fig. 2. The gradient road was modeled on the gradients of 1% to a maximum of 12% of an ordinary road.

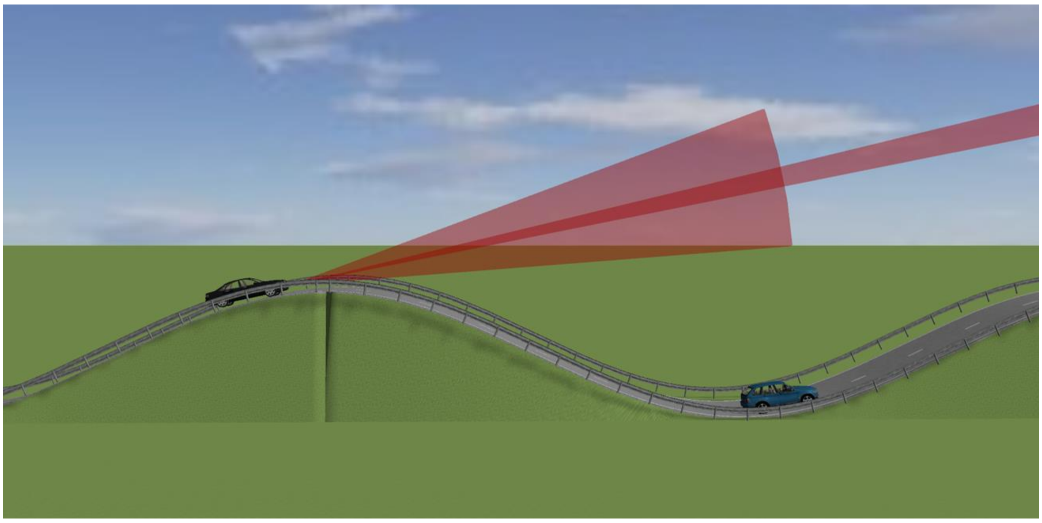

Fig. 1 Performance limits of vehicle radar on roads with an up-down road gradient

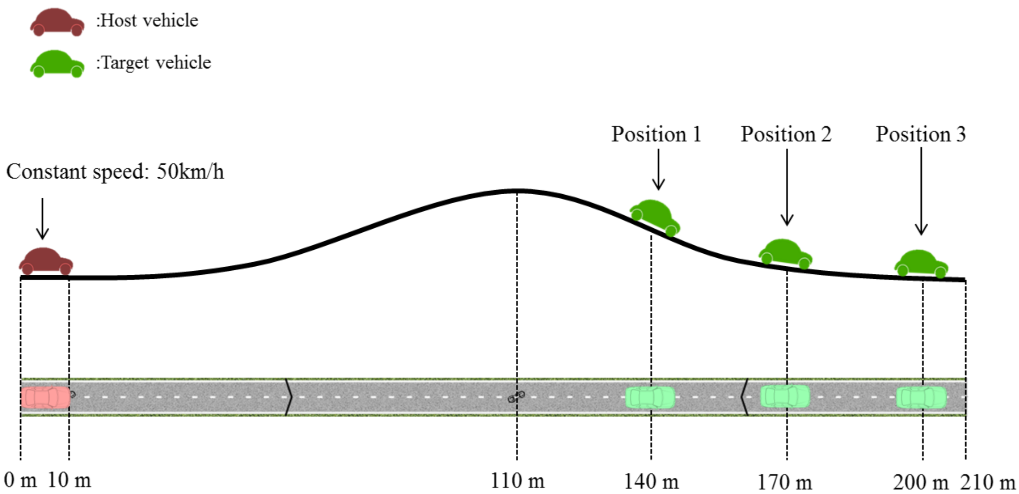

Fig. 2 Simulation scenario

The target vehicle was simulated at positions 1, 2, and 3 at varying road gradients. The radar specifications and vehicle sizes used in the simulation are given in Table 1, and the radar mounting position is shown in Fig. 3. In this study, the collision risk between the host vehicle and the target vehicle is expressed as the time-to-collision (TTC). Here, the TTC is calculated as the ratio of the relative speed and the relative distance of the target vehicle; as this value decreases the collision risk increases. Furthermore, based on the value of the TCC, the warning level of the FCWS identifies the risk stage, and the warning level according to the TTC is given in Table 2.

Table 1. Simulation configuration parameters

Name	Parameter	
Short-range radar	Detection range (m)	0.2-30
	FoV (°)	Azimuth: ±40
		Elevation: ±15
Long-range radar	Detection range (m)	20-200
	FoV (°)	Azimuth: ±10
		Elevation: ±2.25
Host vehicle	Width (mm)	2,029
	Height (mm)	1,447
Target vehicle	Width (mm)	2,178
	Height (mm)	1,716

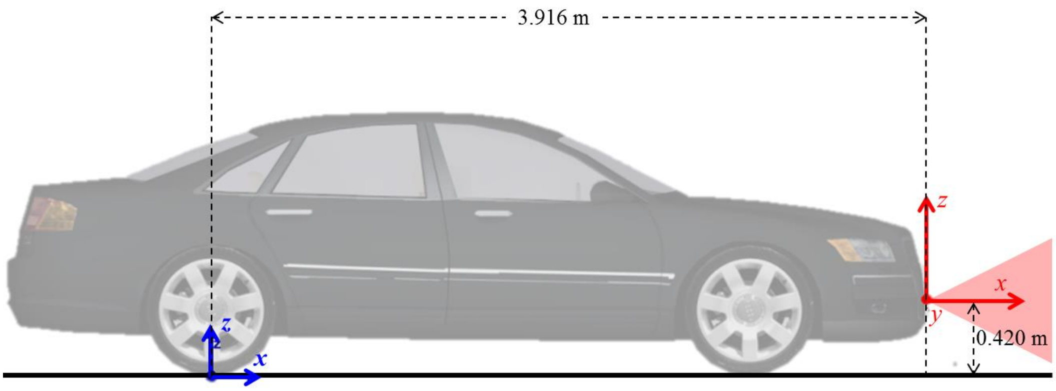

Fig. 3 Position of radar sensor mounted on host vehicle

Table 2. Warning level of FCWS

Warning level	1	2	3
TTC (s)	≤ 2.7	≤ 1.7	≤ 0.8

2.2 Simulation results

Table 3 shows the radar detected relative distance range between the host vehicle and the target vehicle for each scenario. At Position 1, the relative distance is seen to gradually decrease with the increasing road gradient. In addition, the radars were unable to re-detect the front target vehicle at Position 3 for each gradient. This range of non-detection arises when the target vehicle departs from the radar range, as its pitch motion changes on a road with a gradient.

The FCWS simulation result for each position on each gradient of the road is shown in Fig. 4. For gradients 1% to 8% (Fig 4(a)–(h)), the FCWS stably generates a warning signal for each stage of the collision risk without a sudden change in the warning level. However, beyond a gradient of 9%, unlike the aforementioned result, the warning level 1 signal is delayed at each position. This delay is due to the limitation in the radar's detection range at sharp gradients greater than 9%, even when confronted with an imminent collision. TCC, which is the basis for the warning level of the FCWS, is the ratio of the relative speed and relative distance, where if the relative speed is greater than the specified value (50 km/h), the FCWS would not be able to operate effectively to warn the driver, and would be unable to prevent an accident.

Table 3. Radar detected relative distance range

Road gradient (%)	Position	Detected relative distance range (m)	Road gradient (%)	Position	Detected relative distance range (m)
1	1	0.2-137.72	7	1	0.2-43.88
	2	0.2-167.89		2	0.2-55.61
	3	0.2-197.77		3	0.2-80.66
2	1	0.2-137.95	8	1	0.2-38.73
	2	0.2-167.73		2	0.2-50.55
	3	0.2-148.42, 149.88-152.74		3	0.2-79.25
3	1	0.2-125.38	9	1	0.2-37.33
	2	0.2-100.99, 102.59-103.22		2	0.2-49.16
	3	0.2-111.68		3	0.2-78.3
4	1	0.2-124.82	10	1	0.2-32.77
	2	0.2-57.27, 70.79-78.84		2	0.2-48.12
	3	0.2-86.08		3	0.2-29.95, 47.16-74.63
5	1	0.2-83.87, 86.15-87.41	11	1	0.2-31.94
	2	0.2-55.82		2	0.2-44.14
	3	0.2-85.91		3	0.2-29.88, 47.21-73.62
6	1	0.2-50.57	12	1	0.2-30.96
	2	0.2-55.84		2	0.2-43.12
	3	0.2-85.25		3	0.2-29.95, 47.32-73.14

3 Conclusion

This study analyzed the performance of the vehicle-mounted FCWS on a road with varying gradients. PreScan was used to model the vehicle-mounted radars and the various gradients. As the target vehicle moved to different positions, the performance of the FCWS was simulated up to the maximum gradient of an ordinary road. The simulation results showed that as the gradient increased, the range of the radar was reduced, and so was its ability to detect the vehicle infront. Furthermore, at gradients greater than 9%, the warning level signal of the FCWS was delayed, regardless of level of risk of collision with the vehicle infront. Therefore, at gradients greater than 9% the FCWS cannot generate an effective warning to the driver when using only vehicle sensors.

The aims of future research are to study the FCWS enhanced with vehicle-to-vehicle communication, as this is believed to be effective in overcoming the limitations of vehicle-mounted sensors on roads with gradients.

Acknowledgements. Foundation item: This research was supported by the MSIP (Ministry of Science, ICT&Future Planning), Korea, under the C-ITRC (Convergence Information Technology Research Center) support program (NIPA-2013-H0401-13-1008) supervised by NIPA (National IT Industry Promotion Agency).

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Received: August 9, 2014