EVALUATION OF THE VISION BASED BLIND SPOT DETECTION SYSTEM MISJUDGMENT PERFORMANCE BASED ON ROADWAY CURVATURE

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ABSTRACT

Even though state of the art technologies in assisting drivers to prevent accident or to minimize damages are currently adopted in most vehicles, few methodologies have been proposed in terms of evaluating the effectiveness and performance of those systems being operated in local roadway environment.
Those assistance systems would warn drivers' lack of awareness or carelessness through proper warning signal but fault or misjudgment in detecting an incidence often discourage customers and drive them away from relying on relevant systems.
The blind spot detection (BSD) system has been designed to warn drivers when adjacent vehicles are out of driver visible sight with close proximity.
At a certain curvature lane, even though a vehicle follows preceding one in the same lane, it would be located in the warning zone and might provoke an alarm.
A study objective is to evaluate the characteristics of BSD system in various curvature roads.
The roadway design standard with flat surface eliminating the effect from elevation is used in introducing curvature road. The vision based BSD system with lane width of 3.5m, lane radius of curvature as 110 and 125m is used. The BSD system detection criteria are applied referring to ISO 17387. The possibilities of system's misjudgment are based on the proportion of current lane area detected by the system within the detection range. The assessment of the area is found from analytical analysis or Monte Carlo method based on the geometry.
The BSD system performance is found to be characterized by lateral and longitudinal detection range, roadway width and curvature. The results show that the possibility of misjudgment increases as the curvature decreases. As the longitudinal detection range increases, erroneous measurement increases gradually and reaches sudden leap. The misjudgment trend with respect to lateral detection range shows similar variation.
The other parameters affecting the system performance might be current and following vehicle orientation, location, lane width, vehicle speed with different inter vehicle gap. Further study is encouraged.
Various calculation methods would be proposed for the assessment of overlapped area composed of lines and arc. Since the combination of geometrical disposition and operating condition would require detailed classification of cases for assessment purposes, more thorough studies are required.
Different roadway design like clothoid curve would require complex evaluation method other than simple analytical approach.
A vision base BSD system might cause malfunction and deteriorate the credibility that the driver assistance system has been accumulating. As for the misjudgment of system, similar analogy can be applied to different type of BSD system like radar based one. Studied results can be used to enhance the system reliability by adjusting the lateral and longitudinal detection range. Proper test procedures considering roadway design criteria and vehicle condition can be proposed for evaluating BSD system performance.

INTRODUCTION

Recently, lots of studies for Advanced Driver Assistant System(ADAS) aiding drivers in order to enhance vehicle safety have been conducted.
As one of many active safety systems, ADAS contributes in preventing accidents and reducing severity of damages. And the numbers of vehicles that adopt ADAS are increasing [1]. The most popular vehicle safety assistance systems that are

currently available are Adaptive Cruise Control (ACC), Automatic Emergency Braking System (AEBS), Lane Departure Warning System (LDWS), Lane Keeping Assistance System (LKAS), Active Head Restraint (AHR), Adaptive Front Lighting System (AFLS), and Blind Spot Detection (BSD)[2]-[7].

The role of BSD is to issue a signal warning a driver against imminent vehicles which are located in the zone where a driver cannot detect. In other words, it prevents an incident caused by a lane change maneuver when a driver cannot recognize adjacent vehicles.

BSD is mostly available to luxurious vehicles. Even though, due to the technological leap of the system, more affordable systems are expected to be available in the near future, tools to evaluate its performance are yet to be developed.

Even though the ADAS is to assist drivers, more studies are needed to be made to solve nuisance problems like frequent warning or false alarm. Most of the problems are caused by misdetection or misjudgment of the system. The misdetection is closely related with environmental elements like climate.

The causes of misjudgment can be related with domestic roadway conditions and sensor detection ranges [8].

At the curved road with minimal radius of curvature, even if an approaching vehicle from the rear is staying in the identical lane with current vehicle, it might be classified as an imminent danger since it is located in the detection zone (Figure 1). A false waning might be issued because of a misjudgment.

Studies for evaluating the characteristics of BSD with respect to various domestic curvature roadway conditions that might cause false alarm due to misjudgment

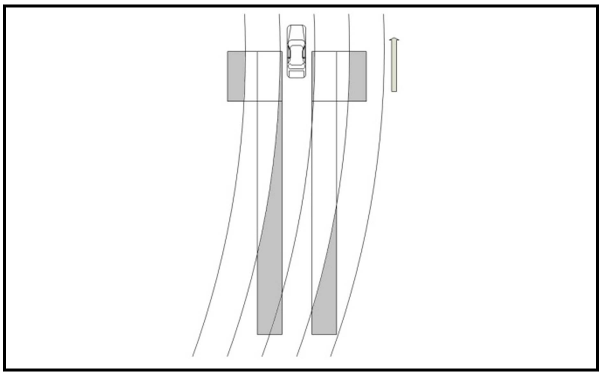


Figure 1. Misjudgment zone of blind spot detection systems

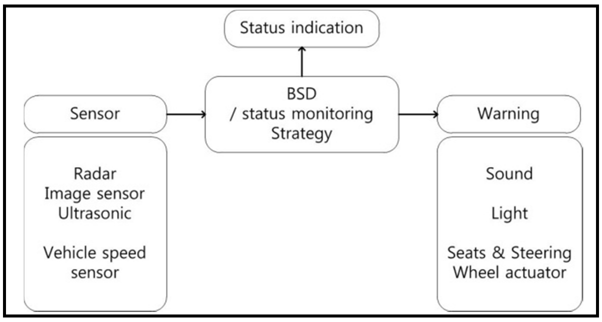
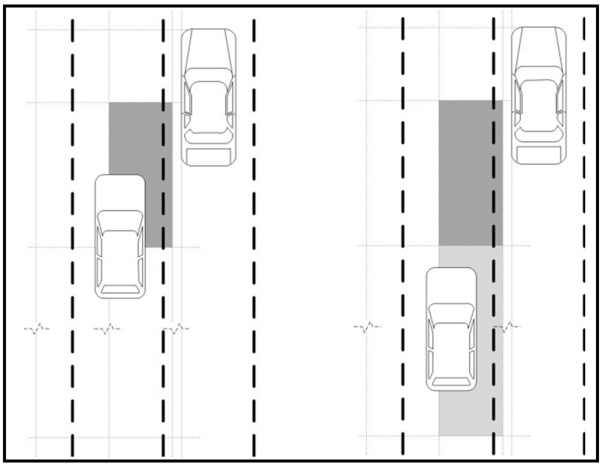


Figure 2. Blind spot detection systems



(a) Adjacent zones **(b) Rear zones**

Figure 3. Coverage zone of blind spot detection

BLIND SPOT DETECTION SYSTEM (BSD)

Typical BSD system has a detector which senses nearby vehicles and a processor which makes a decision based on collected data and issues a warning if necessary (Figure 2). In detecting vehicles, either optical or radar type are most frequent one[9]. The sensor detects closing vehicle speed and its relative distance. The processor monitors the whereabouts and movement of vehicle. If the vehicle is located in the warning zone, the system would decide the imminence of the detected vehicle.

The types of waning could be visual, audio and haptic. The detect zones defined in ISO 17387:2008 are adjacent zones and rear zones[10]. If any vehicle arrives to the predefined adjacent zone, a proper warning signal should be issued.

Contrast to that, a warning might not be followed depending on the BSD system when other vehicle is located in the rear zone.

ROAD ALIGNMENT

The fundamental design rule for roadway structure configuration includes road assortment, design speed and geometry structure.
Elements of roadway geometry structure including radius of lead curve, incline, super elevation, sight distance, rate of vertical curvature are the key factors governing the vehicle safe operation.
Along with the road design factors, roadway combinations along the longitudinal direction as straight line, transition curve and circular curve are properly allocated to accommodate vehicle operation. Vehicle factors affecting the roadway design are vehicle specification and vehicle speed. Typical vehicle data among available specifications are dimension of vehicle width, height, weight and wheel base distance (Table 1 for full size passenger vehicle). Depending on the vehicle speed that the roadway can accommodate, roads are classified as stated in Table 2.
According the roadway design criteria, minimum lane width is defined depending on the vehicle speed allowed in rural and urban area (Table 3).

METHOD OF MISJUDGMENT ZONE

Simulation Factors

The roadway specification is introduced base on ISO 17387 test condition. The vehicle test speed recommended in ISO 17387 is 72km/h. In order to guarantee the proper operation and detection of false warning in the curvature road, lane width of 3.5m is selected. The radius of curvature in ISO 17387 is defined to be 3 types as 125m, 250m and 500m depending on the other vehicle's closing speed. In practice, the actual roadway radius of curvature varies depending on the road sector reflecting nearby environment. In the exit, the minimum radius of curvature is set to be 110m for the speed of 60km/h[11]. Therefore, minimum radius of curvature as 110 and 125m reflecting the practical and ideal design criteria would be applied in the study. The vehicle type for the study is chosen to be the most popular full size passenger car. Driver's observing reference for the study is assumed to be at 3.66m from the vehicle front[12].

Assumption

Following assumptions are introduced for the simulation:

1) No malfunction in BSD device operation
2) Only the horizontal elements are considered in order to observe the characteristics of the BSD detection range with respect to the roadway geometry under the horizontal linear roadway design criteria.
3) The radius of curvature is decided based on the vehicle speed and lane width of the road
4) Vehicles are operated in the midst of the lane.

Selection of factors

Key parameters used for BSD simulation to evaluate its benefit in terms of reducing traffic accident are as follows:

1) Only the curvature factor is introduced among many available elements in horizontal linear roadway design criteria
2) The radius of curvature data are 110 and 125m.
3) Roadway is 3.5m in width and number of lanes are three
4) Vehicle type is full-size passenger car
5) The detection zones are based on ISO 17387 specification.
6) Full-size passenger cars eyellipse is located at 3.66m from the vehicle front

Table 1.
The specification of design vehicle

(m)	Width	Height	Length	Wheel base
Mid-size Passenger cars	1.7	2.0	4.7	2.7
Full-size passenger Cars	2.0	2.8	6.0	3.7
Trucks	2.5	4.0	13.0	6.5
Semitrailers	2.5	4.0	16.7	4.2 / 9.0

Table 2.
The Design speed of road

Road	Design speed (km/h)
Highway	100
Major Arterial	80
Minor Arterial	60
Collector Road	50
Local Road	40

Table 3.
The Design speed and lane width

Road	Design speed (km/h)	Minimum width of the road (m)	
		Province	City
Highway	≥100	3.50	3.50
road	≥80	3.50	3.25
	≥70	3.25	3.25
	≥60	3.25	3.00
	60≥	3.00	3.00

RESULTS

The BSD detection ranges can be stretched toward either longitudinal or lateral direction. With these configurations, there is a possibility that erroneous detection can occur due to the combination of roadway curvature and straightness of BSD range. Also the combination of roadway geometry and vehicle heading would produce different error results depending on either side of the vehicle.
The possible misjudgment zone as in Figure 1 can be defined as the overlapping area between the vehicle operation lane and the BSD system detection range. Therefore, rate of misjudgment can be evaluated by calculating the proportion of the zone with respect to the whole detected area. The area of misjudgment zone can be calculated by using either mathematical formula to be developed or geometrical configurations. In this process, factors like detection range, lane width and vehicle width are considered. Additional roadway design elements like clothoid shape instead of simple circular formula would add complexity to the simulation.
The misjudgment area is calculated using Monte

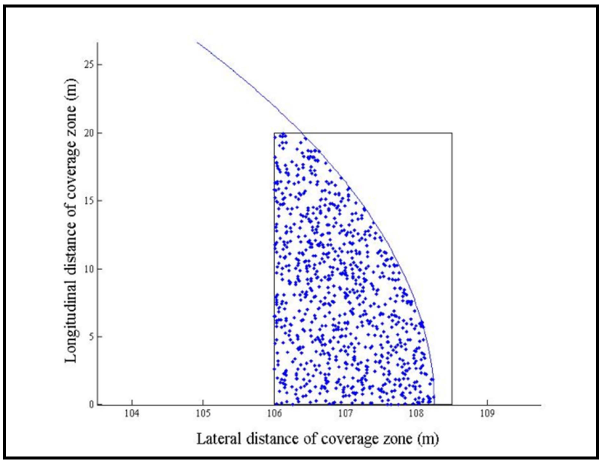


Figure 4. Misjudgment zone calculate by Monte Carlo integral

Carlo integral method as in Figure 4 using random numbers and assessing every counts falling in the designated zone. The BSD lateral detection range is stretched from the vehicle side to the maximum while the longitudinal detection range is extended from the eyellipse. The range increments introduced for the simulation are 0.5 and 1m for lateral and longitudinal direction respectively.
The result of misjudgment area rate towards longitudinal direction is displayed in Figures 5~8 while that towards lateral direction is shown in Figures 9~12 for the radius of curvature as 100 and 125m. Along each direction, at each incremental point unit square areal patch is examined to produce proportion of misjudgment area. Accumulated results are also displayed to evaluate the trend of misjudgment area.

The BSD system misjudgment possibility increases along the longitudinal direction as its range increases. As soon as the BSD system range reaches 25m in the longitudinal direction, all unit areal patch displayed that all detected result are false. As stated earlier, lateral directional characteristics in each side are not identical since the roadway environments on each side with respect to the vehicle are neither identical nor symmetrical.

The rate of misjudgment area on the left had side of the vehicle increases rapidly after the range of 10m (Figs. 5~6) while that on the right happens after 18m (Figs. 7~8). Since the simulation is based on the case where vehicle is driven to bear left, the possibility of misjudgment on the left is greater than that on the right. It would be vice versa. It refers to the result that the rate of misjudgment is naturally related with the roadway geometry.

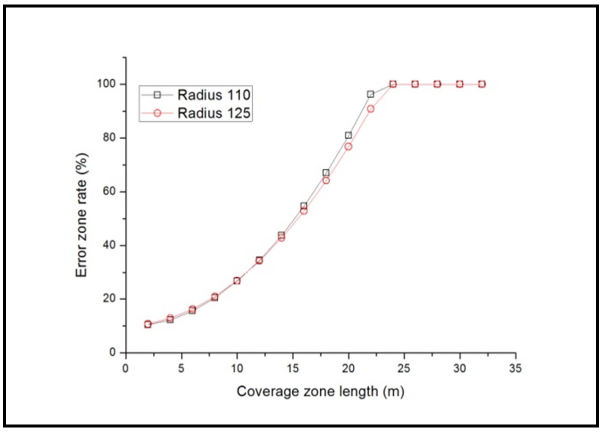


Figure 5. Error area rate of misjudgment zone per meter (longitudinal distance of left side)

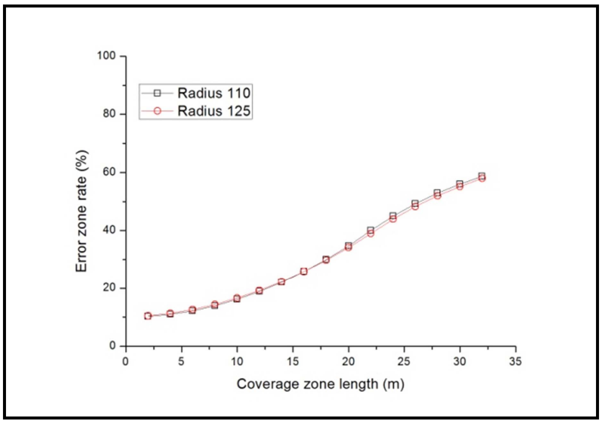


Figure 6. Misjudgment zone error rate for detection range (longitudinal distance of left side)

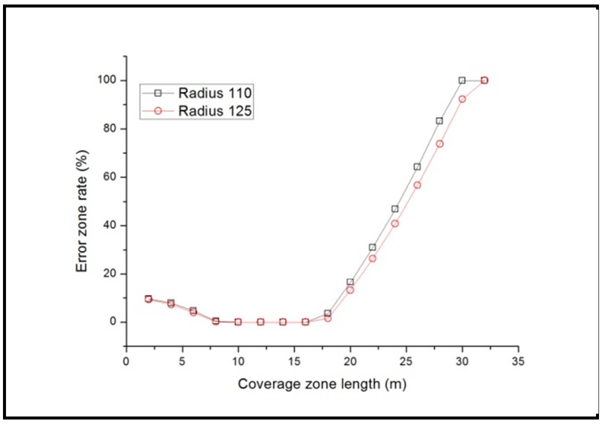


Figure 7. Error area of misjudgment zone per meter (longitudinal distance of right side)

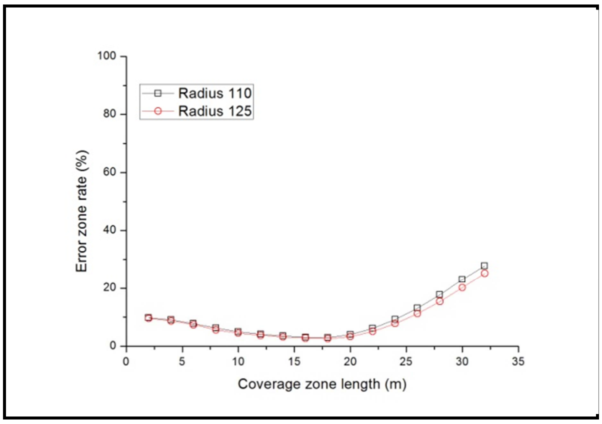


Figure 8. Misjudgment zone error rate for detection range (longitudinal distance of right side)

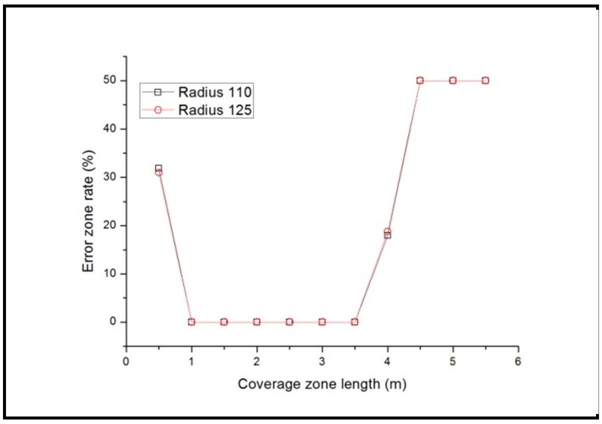


Figure 9. Error area rate of misjudgment zone per meter (lateral distance of left side)

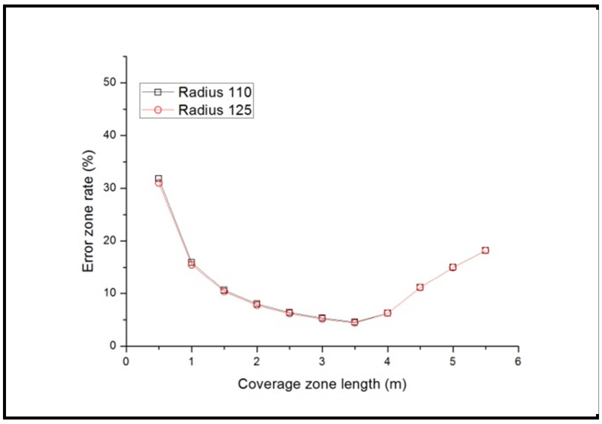


Figure 10. Misjudgment zone error rate for detection range (lateral distance of left side)

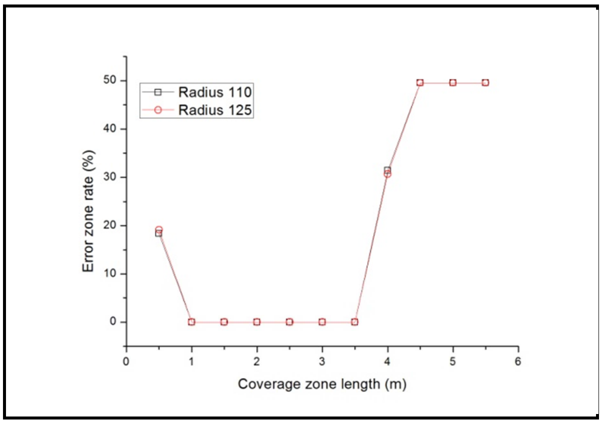


Figure 11. Error area rate of misjudgment zone per meter (lateral distance of right side)

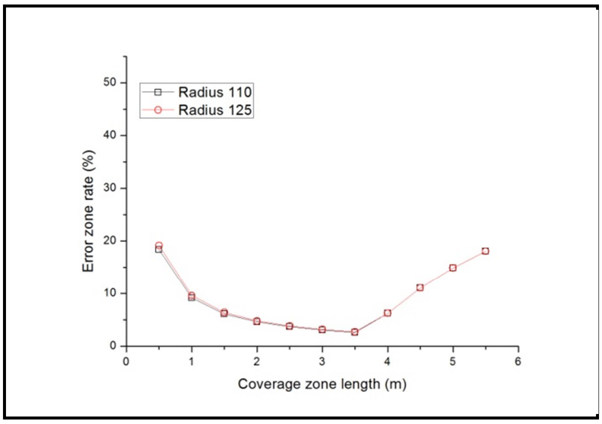


Figure 12. Misjudgment zone error rate for detection range (lateral distance of right side)

The results of lateral direction misjudgment rate are in Figures 9~12. The left side lateral directional results are in Figures 9 and 10 while those of right hand side are in Figures 11 and 12.

The trend of misjudgment rate shows that as the detection range increases the rate drops initially and then increases. The rate on either side varies almost identically with sudden increase after 3.5m detection range. Within the range in between 1m and 3.5m, no misjudgment would be expected since those ranges belong to the lane range next to the current vehicle.

The rate increases rapidly after 3.5m since the range stretches beyond the lane next the current vehicle. All vehicles detected in this range should not provoke a warning.

The accumulated rate trend displays almost identical trend except in the initial range. Actually, the rate observed on the vehicle's left shows minutely higher result compared to that seen on the vehicle's right. This is again the vehicle is driven on the road bearing to the left.

As for the radius of curvature effect between 110m and 125m, higher rate of misjudgment is observed in smaller curvature road.

CONCLUSIONS

The BSD system detection range characteristics have been analyzed for various roadway conditions. Misjudgment zone has been calculated considering linear roadway design factors and BSD system detection ranges. Detailed simulation has been conducted using Monte Carlo method. The major studied results can be summarized as:

1) The major factors affecting misjudgment are radius of curvature and BSD detection range.
2) The level of misjudgment rate could be assessed based on BSD detection range when the vehicle is on the curvature road.
3) Non-symmetric results for longitudinal detector range study results due to the roadway curvature direction would greatly contribute to enhance the system performance.
4) More elaborated implementation of BSD system is recommended in curvature road.
5) The longitudinal direction misjudgment rate results could be applied to set the maximum allowable detector range to prevent false reading.
6) The study results along lateral direction could be applied to limit the range of BSD system detector laterally.
7) More elaborated studies are required to assess the system performance reflecting more practical driving environment with external perturbation while driving.

ACKNOWLEDGEMENTS

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