

Rear-end Collision Velocity Reduction System

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ABSTRACT

Through the use of traffic accident statistics and questionnaire surveys, some causation factors for rear-end collisions were obtained. Next, accident analysis was performed through simulations based on these factors. The results indicated that many rear-end collisions are caused by momentary inattention during daily driving. Therefore, a collision avoidance assist system was developed that can be useful in these situations. In developing this system, a warning timing that does not interfere with the driver was set so as to reduce the potential for a less effective warning, and a system structure was adopted where delays in recognition and judgment are compensated for by automatic braking. The automatic brake activation method was investigated through calculations and actual vehicle tests. The activation timing was set so as not to interfere with normal driver operations, and the deceleration rate was set to assist the driver's avoidance operations. As a result, the basis for a system to help reduce rear-end collisions was developed. Further development is needed to bring this kind of system to the point of practical application.

1. Introduction

Various systems have been proposed by different companies for the Advanced Safety Vehicle (ASV) project promoted by the Ministry of Transport (since 2001 known as the Ministry of Land, Infrastructure and Transport). These proposals include the use of radar and other technologies for sensing the external environment to determine conditions in the surroundings and make judgments accordingly to help reduce traffic accidents from occurring or to reduce accident severity. The ASV project is now entering its second phase.

Systems using radar, cameras, and other such external environment sensing technologies to predict collisions with preceding vehicles and apply automatic braking to help reduce collisions from occurring have been proposed since Phase 1 of the ASV project. However, due to technical and conceptual difficulties such systems have not reached the point of practical application.

Instead of total automatic collision avoidance, the present system concept is a collision avoidance assistance system centered on the driver and limited to applications to rear-end collisions. This paper reports on the development of this system.

2. General accident analysis

First we analyzed 1997 traffic accident data. The analysis of traffic accidents involving death or injury in 1997 shows that rear-end collisions make up approximately 30% of the

total accidents (Fig. 1).⁽¹⁾⁽²⁾ Then the characteristics of rear-end collisions were analyzed.

Fig. 2 presents the frequency of rear-end collisions in relation to the speed at which the driver recognizes the danger. This indicates that more rear-end accidents occur at low and medium cruising speeds. Fig. 3 shows the human factors of the persons principally concerned who caused the accident. This data indicates that recognition failure caused by inattention to the conditions ahead is often the cause of

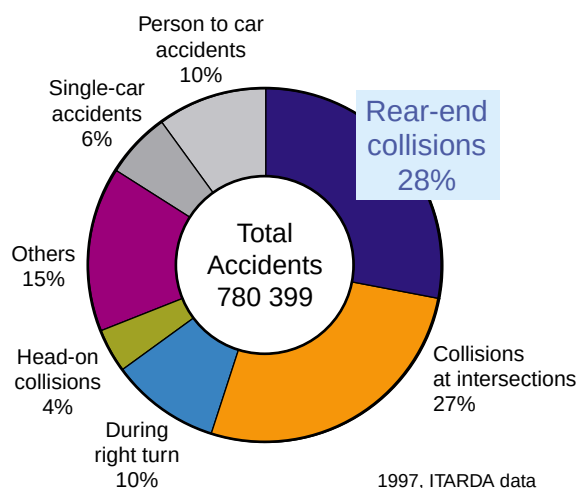


Fig. 1 Composition of traffic accidents per year (1997)

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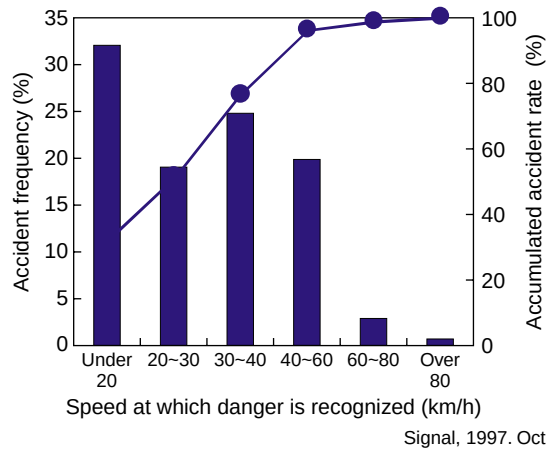


Fig. 2 Frequency and accumulated rate of rear-end collisions in relation to the speed at which danger is recognized

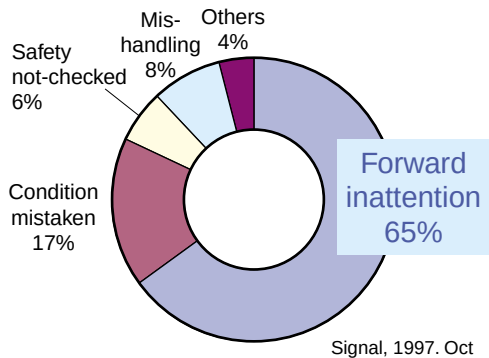


Fig. 3 Factors in rear-end collisions

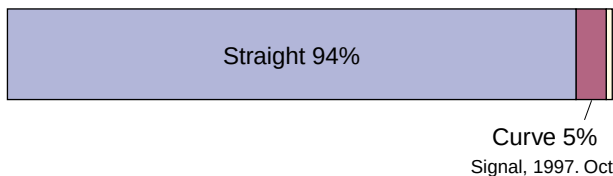


Fig. 4 Road situation during rear-end collisions

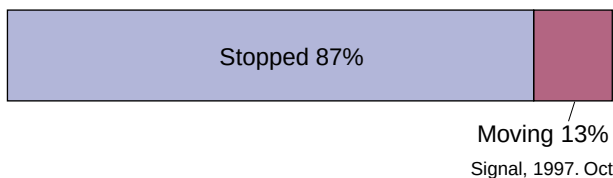


Fig. 5 State of vehicle ahead during rear-end collision (according to statistics)

rear-end collisions. Fig. 4 shows the road type at rear-end collision locations, which indicates that approximately 90% of these accidents occur on straight roads while the number occurring on curves is extremely small. Fig. 5 indicates the state of the preceding vehicles involved in these rear-end collisions. Approximately 90% of rear-end collisions are with stationary vehicles.

The above accident analysis suggests that a common scenario for the occurrence of rear-end collisions is delayed recognition of a preceding vehicle due to inattention to the conditions ahead while driving at low to medium speeds on a straight road.

3. Analysis of accident conditions

3.1 Questionnaire survey

We conducted a questionnaire survey to investigate the conditions that were involved when actual accidents took place.

The survey was provided to 57 people within Honda who had actually caused rear-end collisions and people who had nearly such accidents.

We began by inquiring about the state of the vehicles hit, and learned that collisions most commonly occurred while the vehicle ahead was still moving (Fig. 6). This contradicts the previous results shown in Fig. 5. Further analysis of the accident conditions indicated, as can be seen in Fig. 7, that approximately half of the cases cited “delay in recognition of deceleration” and “greater deceleration than

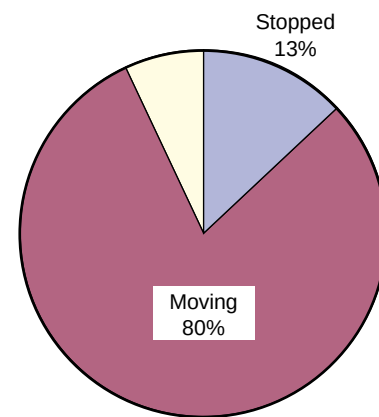


Fig. 6 State of vehicle ahead during rear-end collision (according to questionnaire)

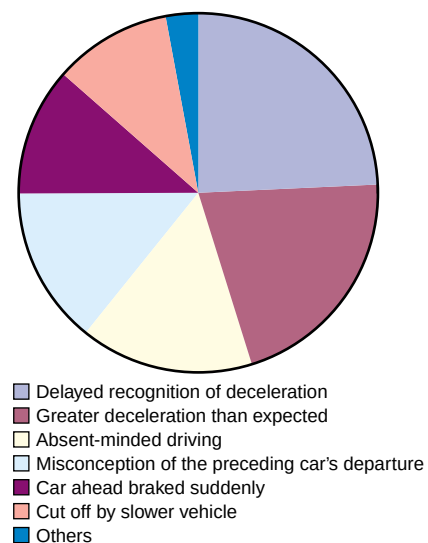


Fig. 7 Factors involved in rear-end collisions (according to questionnaire)

expected” as factors in causing or nearly causing a collision. In other words, the cause was not that the driver had failed to watch the road ahead for too long a time. Instead, that the driver knew there was a vehicle ahead but neglected to pay sufficient attention, and thus caused or nearly caused a rear-end collision.

3.2 Simulation analysis

An analysis was then carried out to determine the degree of inattention that resulted in these accidents, taking into account the general accident analysis and the questionnaire survey results. That is, it could be considered understandable if a rear-end collision followed some degree of prolonged inattention due to, for example, drowsiness. The large number of accidents, however, made it unlikely that the majority of drivers were experiencing such prolonged inattention, nor did the questionnaire survey uncover anything to support such a factor.

Consequently, we used simulation to investigate the possibility that the accidents could have been caused by short-term or momentary inattention.

Under the simulation scenario, we hypothesized that drivers were momentarily inattentive as they followed the preceding vehicle, which decelerated during this very moment of inattention. This possible scenario was determined based on the questionnaire, according to which the majority of accidents occurred under these circumstances.

The scenario conditions specified a vehicle headway time in relation to the preceding vehicle (equal to the distance between the vehicles divided by the subject car speed) of 1.5 seconds, with the accident occurring when the vehicle ahead decelerates (deceleration of 0.3 G) in the instant when the subject car driver is inattentive. After a set period of 1, 1.5, and 2 seconds of inattention, the driver pays attention forward, recognizes what is happening, makes a judgment, and acts to decelerate. The driver’s response time (the time from the start of attention to the beginning of deceleration) at this point is set at 1.3 seconds.⁽³⁾⁽⁴⁾ At the time an action to decelerate is taken, the deceleration is 0.8 G. The simulation was carried out with three different levels of driver inattention.

Fig. 8 presents the simulation results. The horizontal axis is the speed of the subject car, while the vertical axis is

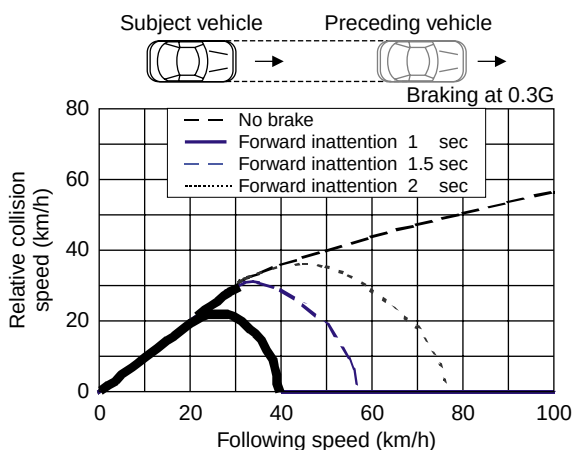


Fig. 8 Results of simulation (while following)

the relative speed at the time of collision. As Fig. 8 indicates, the period of inattention makes a difference. A rear-end collision takes place when driving at low to medium speeds, and a collision does not take place when driving at higher speeds. This result is in line with the results shown in Fig. 2, which shows that the majority of rear-end accidents occur at low to medium speeds. The bold line in Fig. 8 represents the situation when the vehicle ahead decelerates to a complete stop and the subject vehicle collides with it from the rear. In the statistics, an accident that occurs in this way with a travelling vehicle that has come to a stop is included in “Stopped” in Fig. 5. The simulation results suggest that the main causal factor in rear-end collisions is not necessarily a prolonged period of inattention alone. Instead, rear-end collisions can also occur as a result of momentary inattention when driving at low to medium speeds.

Another simulation was then carried out with the scenario of a rear-end collision with a stationary vehicle. This simulation was conducted using a parameter defined as the number of seconds in advance that the driver recognized the stationary vehicle. Fig. 9 shows the results when the driver takes action to decelerate in the specified response time (the 1.3 seconds explained above) after recognizing the stationary vehicle. Examination of these results shows that a rear-end collision will not take place at low to medium cruising speeds when recognition takes place 2 - 2.5 seconds before collision. A rear-end collision will only take place if the driver has been inattentive for a considerable time regarding a vehicle that has already come to a stop, and only recognizes the situation approximately 2 seconds before collision. It seems unlikely that there are many drivers of this kind.

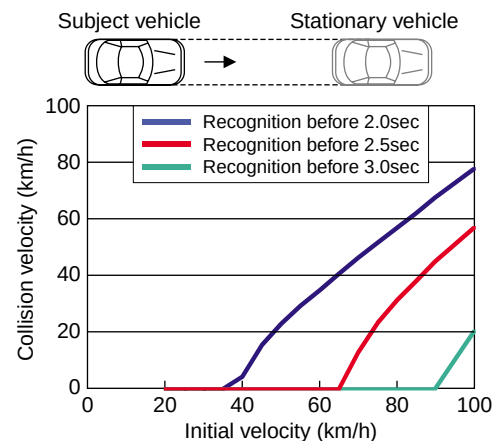


Fig. 9 Results of simulation (with stationary vehicle)

3.3 Period of inattention while driving

An eye camera was then used for measurements to determine the extent of inattention to the conditions ahead during ordinary driving (Fig. 10). This measured the time spent checking for safety, operating the audio system, and performing other actions ordinarily taken during driving that involve looking away from the front. The horizontal axis in the graph shows the forward inattention duration, and the

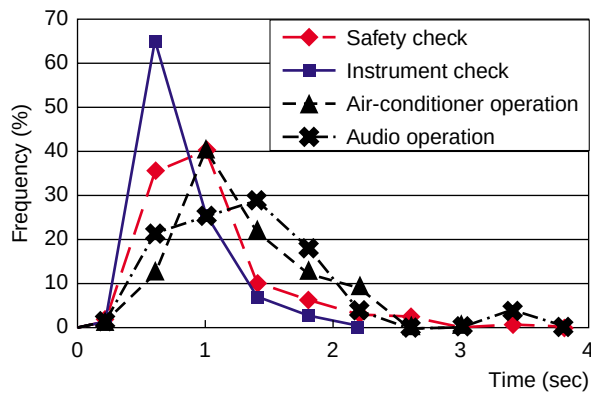


Fig. 10 Forward inattention duration

vertical axis shows frequency of occurrence. As the results in Fig. 10 show, ordinary actions such as operating the audio system or checking instruments can result in momentary inattention of 1 - 2 seconds. It is possible that if the preceding vehicle were to decelerate during the seconds of forward inattention caused by ordinary actions, that a rear-end collision could result. This can be considered the cause of many rear-end collisions that occur at low to medium cruising speeds. Based on the above analysis results, the objective of this research project was set as the development of a basis for a collision avoidance assist system that would be useful in the avoidance of rear-end collisions caused by the inattentiveness of the driver occurring even during normal driving. The system was developed as a collision avoidance assist system rather than an automatic avoidance system in order not to contribute to unsafe driving or invite driver overconfidence.

4. System concepts

4.1 Concepts of a warning and automatic brake system

A warning system was first considered to provide the driver with recognition assistance by means of voice messages or other warnings during times of possible collisions. In this case, it is necessary for the warning to function with timing that allows leeway for the driver to hear the warning, make a judgment, and carry out a maneuver.

Consequently, driver response time to warnings was analyzed using a driving simulator. The test was set up so that the driver would look off to the side while driving behind a vehicle moving ahead. During that time, the forward vehicle would decelerate, and a warning would sound 2 seconds before the predicted collision. Fig. 11 shows the response time that elapsed between hearing the warning sound and initiating braking. From this a response time of about 0.6 - 1.4 second is needed. In the case of a warning system, therefore, it is necessary to sound the warning with a timing that allows for this response time as well as the time required by drivers to decelerate their vehicles.

When extra time is allowed in order to adapt to a larger number of drivers, however, the alarm may sound frequently in normal situations. There is the risk that drivers would then become accustomed to the warning, so its intended

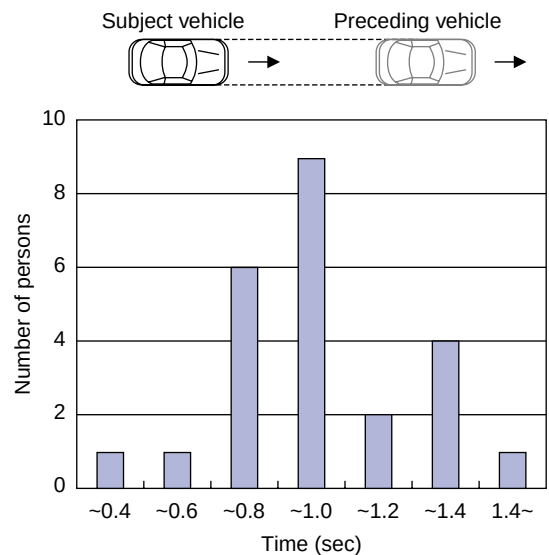


Fig. 11 Driver's response time (by driving simulator)

effect could end up being diminished. On the other hand, when the warning timing is reduced, there is less of a time margin for judgment and action after hearing the warning. Therefore, there is a possibility that the warning will not be fully effective.

This system, therefore, also utilizes automatic braking to further help assist the driver in avoiding a collision. The timing for the activation of the warning was set to try to minimize interference with the driver during normal driving operation so as not to minimize the effect of the warning. The system was also configured with automatic brakes to help compensate for delays in judgment and action by the driver.

4.2 Study of the control timing

The distance required for collision avoidance by braking alone is ordinarily greater than that required for collision avoidance by steering. The attempt to avoid a collision with certainty by means of braking alone, therefore, may in some cases interfere with the driver's evasive steering maneuvers.⁽⁵⁾

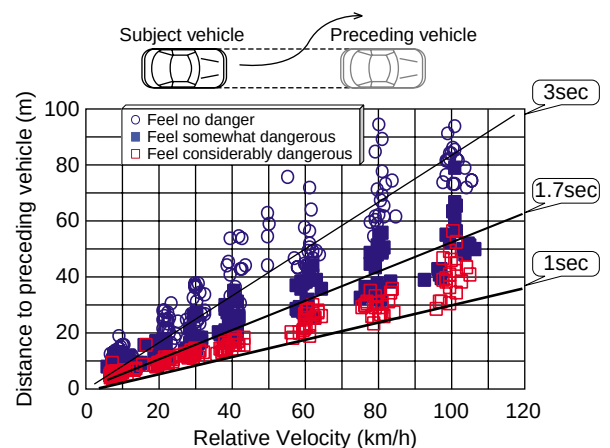


Fig. 12 Avoidance operation timing test

We then studied the timing for system operation by measuring the actual timing of evasive steering actions taken by drivers. Fig. 12 shows the results for measurement of distance from the preceding vehicle at the time evasive steering action is initiated with respect to the car's relative speed of approach to the preceding vehicle. The horizontal axis shows the relative speed and the vertical axis shows the distance at the time avoidance operations are initiated. The symbols in the graph indicate the points at which the driver felt the need for avoidance operations were feel no danger, feel somewhat dangerous, and feel considerably dangerous (at the limit for such operations). The lines in the graph show the margin of time before collision (equaling the distance between vehicles divided by their relative speed).

The above findings led to consideration of the two points below with regard to the timing for activation of a warning in this system. The first was that frequent warnings should not make the driver so accustomed to warnings that the warning becomes ineffective. The second was that drivers should not be encouraged to rely excessively on the warnings to the point that they feel inattention would be permissible until a warning is sounded. Taking this perspective, we decided to set the timing for warnings so that they would not occur frequently during ordinary driving, but would be generated approximately 1.7 seconds before the predicted collision when involving avoidance operations the driver considers somewhat dangerous. The timing for the automatic braking (termed emergency braking) was set to avoid interference with driver operations as much as possible and when involving avoidance operations the driver considers considerably dangerous. The timing was set at approximately 1 second before a predicted collision, which would activate the brakes rarely in ordinary driving.

4.3 Automatic brake setting concept

The timing for the activation of the warning is set at the point where ordinary avoidance operations would be initiated, which is the point where danger of collision is increasing, so the warning must be recognizable by the driver. It was decided, therefore, that the warning should not consist of sound alone, but should also include mild automatic braking to warn the driver through a physical

channel. This was termed warning braking. Various studies and experiments regarding the intensity of the warning braking (its deceleration) were conducted repeatedly, and the appropriate value was determined to be about 0.1–0.2 G. At this setting, the brakes would enhance the warning effect in conjunction with the sound while also compensating for any delay in deceleration operations by the driver. In addition, this setting should not interfere with the driver's ability to perform avoidance steering operations.

The next point to consider was the amount of deceleration by the automatic brakes that operate approximately 1 second before a predicted collision (termed emergency braking). One approach was to apply the maximum amount of automatic braking, since the situation was a predicted collision. However, experiments verified that with the inclusion of deceleration from the use of warning braking, the combined use of deceleration plus evasive steering operations would make it more possible to avoid collision. When setting the amount of emergency braking, therefore, we took into consideration how the activation of emergency braking would alter driver attitude and other factors, and how it would thereby affect the driver's evasive maneuvering. The system is also set up to consider the braking force applied by drivers when they recognize a dangerous situation in addition to the automatic braking force.

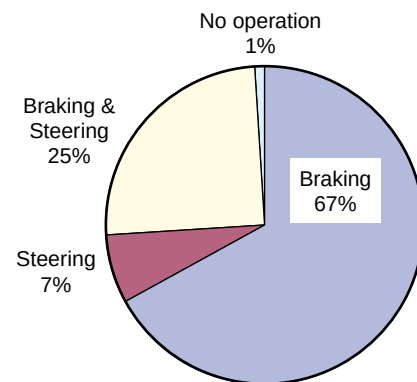


Fig. 13 Avoidance operation during a rear-end collision

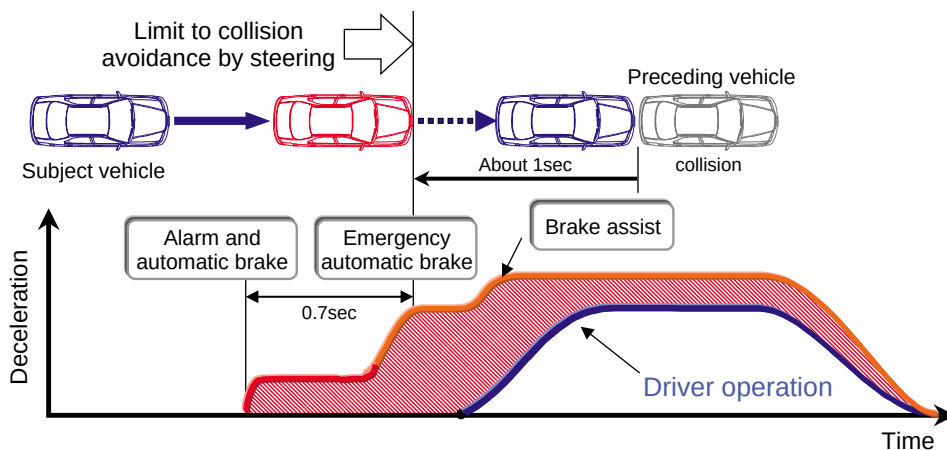


Fig. 14 System operation

The questionnaire results show that when drivers caused or nearly caused a rear-end collision, approximately 70% of them applied the brakes (Fig. 13). The combination of driver operations and automatic braking was, therefore, considered to bring about the appropriate amount of deceleration. Deceleration by automatic braking also increases the margin of time before a collision, thus providing the driver a greater margin of time for judgment and action. This could be expected to have the effect of making the application of the brakes by the driver more likely even for those drivers whose slower response times for making judgments and taking action made them previously less able to apply their brakes. Fig. 14 presents the sequence of system operation modes.

5. System overview

5.1 System configuration

The system configuration is shown in Fig. 15. Millimeter wave radar, which excels at environmentally-resistant sensing, was used for locating vehicles to the front. Table 1 presents the major specifications. The range is about 100 m, which provides detection capabilities approximately 3 seconds in advance at a relative speed of 100 km/h. The detection angle extends 16° to left and right to provide detection of preceding vehicles on straight and gently curving roads.

The system is equipped with a wheel speed sensor to measure the subject vehicle speed and a yaw rate sensor to measure the amount it turns. Using these quantitative vehicle condition values, the system extrapolates the course of the subject vehicle as shown in Fig. 16 and estimates the amount of the subject vehicle's lateral travel at the location of the obstacle. In addition, the system is equipped with a warning

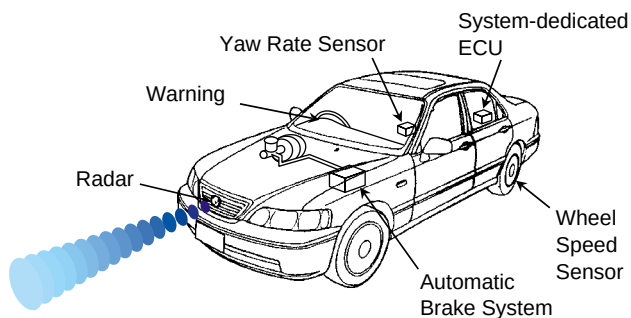


Fig. 15 System configuration

Table 1 Major specifications of the radar sensor

Detection Area	Horizontal Vertical	280 mrad 66 mrad
Maximum Range		100 m
Range Resolution		0.1 m
Range Accuracy		±1.0 m
Sampling Time		0.1 sec

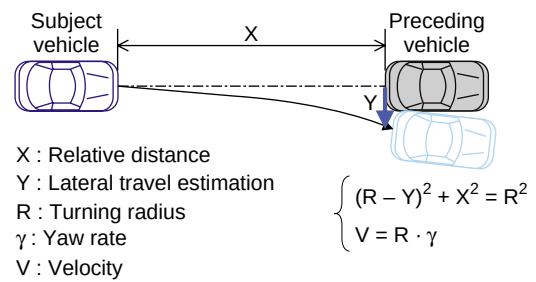


Fig. 16 Prediction of the vehicle locus

unit that warns the driver when the system goes into operation. A hydraulic actuator is also installed to activate the automatic brakes.

5.2 Control logic

Fig. 17 presents the basic flow of system control.

The system recognizes preceding vehicles in the front by radar, and then determines the relative distance to the subject vehicle ($X1$), relative speed, and angle of direction. It also estimates the subject vehicle's course using the speed and yaw rate measurements, and calculates the estimated amount of lateral travel. Then it uses the location of the obstacle and the estimated amount of lateral travel of the subject vehicle to determine the amount of overlap between the subject vehicle and the obstacle, after which it determines the amount of lateral travel (Y) required by the subject vehicle so that it can be steered away to avoid the obstacle. The system then calculates the relative distance ($X2$) required to carry out that lateral travel. The calculated distance and the relative distance to the obstacle are used then to judge

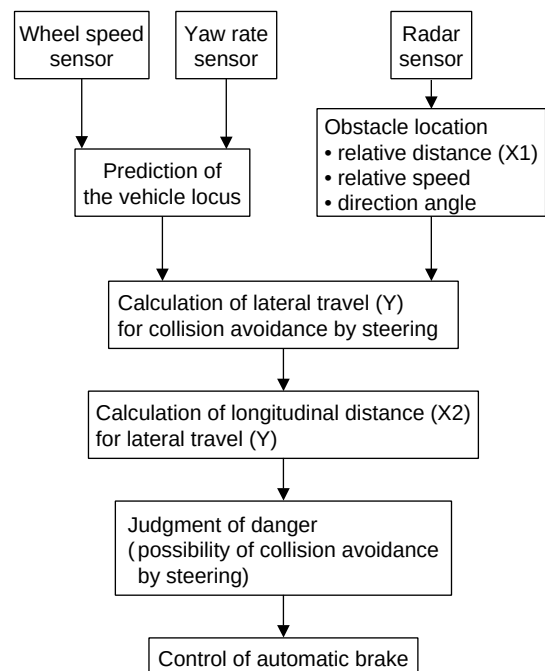


Fig. 17 Block diagram of basic control

the danger and carry out automatic braking control and warning. When $X1$ becomes shorter than $X2$ ($X1 < X2$), automatic braking is activated.

With the physical relationship between the subject vehicle and the preceding vehicle determined in this way, the lateral amount of avoidance achieved by steering will differ between situations when the subject vehicle is located immediately behind the preceding vehicle (full overlap) and when it is located in an offset location. Therefore, the system makes its judgment by replacing this difference in the lateral amount of avoidance by steering with the danger value.

6. System effectiveness

6.1 Simulation results

Simulation was used to demonstrate the system's usefulness in operation. A comparison with system operation using only the warning (by sound) was also carried out in order to determine the additional effectiveness of automatic braking. The response time for driver brake operation after hearing the warning was set at 1 second, which is the average value for the response times with the driving simulator shown in Fig. 11. The emergency braking activation deceleration when the system goes into operation was set at 0.6 G.

The simulation used a scenario in which the preceding vehicle decelerates with the subject vehicle behind it. The simulation conditions specified a vehicle headway time of 1.5 seconds, when following the preceding vehicle, and a 0.3 G deceleration by the preceding vehicle. The deceleration of the preceding vehicle generates a relative speed between it and the subject vehicle; as the relative distance between the vehicles decreases the danger of collision increases. At a point in this range, the system initiates operation. The driver is considered to operate the brakes 1 second after hearing the first warning sound, and the deceleration at the time of driver operation is 0.8 G. The results are shown in Fig. 18. The horizontal axis is the speed of the subject vehicle when following, and the vertical axis is the relative speed at the time of collision. Figure 18 indicates that rear-

end collisions can be reduced when driving at low to medium speeds, and that the collision speed is lowered at higher speeds, when the system has automatic braking. These results and the results in Fig. 2 suggest that it is possible to reduce rear-end collisions caused by momentary inattention.

When the simulation allowed only for the warning (by sound) without any automatic braking, the collision speed is lowered by a smaller amount than when the system has automatic braking, even when assuming the same driver response time (1 second) for applying the brakes after hearing the warning (by sound). Use of only the warning system, therefore, requires earlier warning timing, confirming the usefulness of the addition of the automatic braking system.

6.2 Actual vehicle test results

The next step was to use an actual vehicle to measure the collision speed reduction effect with respect to a stationary object. The test method involved placing an obstacle representing a vehicle directly in front of the subject vehicle, which drives toward it. The system initiates operation when the danger of collision increases. Here, too, the driver carries out braking operations approximately 1 second after the warning. Other system's parameters are the same as the simulation.

The test results are shown in Fig. 19. The horizontal axis is the relative speed (subject vehicle speed), and the vertical axis is the speed at the time of collision. These results indicate that rear-end collisions can be reduced at low to medium driving speeds, where the relative speed is low, and collision speed is reduced at higher speeds, where the relative speed is high.

In both the simulations and the actual vehicle tests, the data indicates that the majority of rear-end accidents occur at low to medium speeds, as shown in Fig. 2. Therefore, this system can be considered to have met the developmental objective of this research project, which was the development of a basis for a collision avoidance assist system that would be useful in the avoidance of rear-end collisions caused by the inattentiveness of the driver.

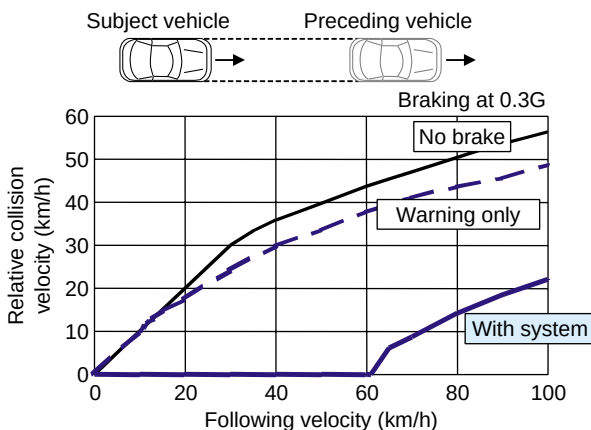


Fig. 18 System effect (according to simulation)

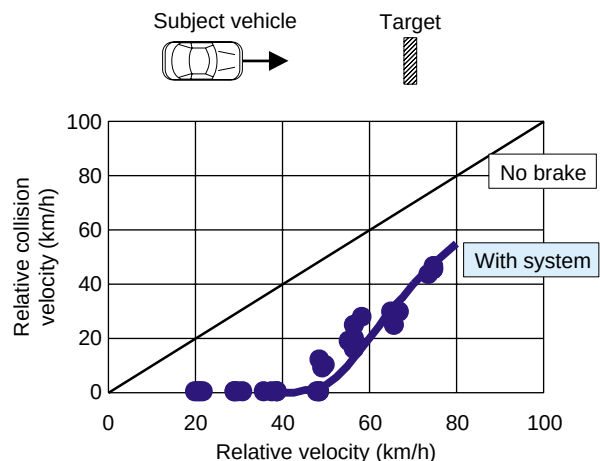


Fig. 19 System effect (according to test results)

7. Conclusion

We carried out development of a system that uses millimeter wave radar technology to sense the external environment in conjunction with a warning and automatic braking system. This made it possible to compensate for delays in the driver's recognition, judgment, and action, making the system useful in reducing rear-end collisions. In developing this system,

- (1) we found that rear-end collisions can occur during ordinary driving as a result of momentary inattention,
- (2) a system was developed to reduce interference with driver operations and support avoidance operations, and
- (3) it was determined that this system is useful in reducing the number of rear-end collisions that take place at low to medium speeds.

However, other issues such as mistaken operation and operational failure also must be analyzed. It will also be necessary to carry out further verification of system reliability under a variety of environmental conditions. In addition, we must take into account changes in awareness on the part of the system users. This present system is a collision avoidance assist system that is intended to do no more than compensate for driver delays in deceleration operations. It is not an automatic avoidance system. It should not have the contrary effect of encouraging unsafe driving by leading drivers to rely entirely on the system. Furthermore, the system cannot prevent rear-end collisions in all situations. Therefore, before bringing this kind of system to the point of practical application we need to address these issues.

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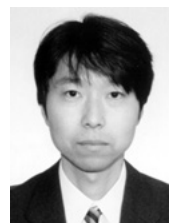
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