Development of Rear Pre-Crash Safety System For Rear-End Collisions

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ABSTRACT

Pre-crash safety systems using radar detecting technology have been commercialized in the market. While the primary focus of these systems have been for frontal collisions, rear-end collisions actually have a higher proportion of the traffic accident injuries in Japan.
In this paper, a new pre-crash safety system for rear-end collisions is explained. It was developed to help alert drivers of vehicles approaching from behind, and also to reduce whiplash injury. This new system uses a millimeter-wave radar installed in the rear bumper to detect a vehicle approaching closely from behind. If it judged that there is high risk of collision, the hazard lights would flash to warn the driver of the approaching vehicle and the headrests are automatically moved forward. Sensors in the headrests detect the location of the occupants' head and shifts the headrests to a closer position to the head before the collision occurs, thereby reducing the risk of whiplash injury. This paper shows the effectiveness of the pre-crash hazard light and pre-crash headrest technology.

INTRODUCTION

According to accident analysis of crashes in Japan, rear-end collisions account for only 4% of fatalities, but approximately 50% of injuries (Fig. 1).

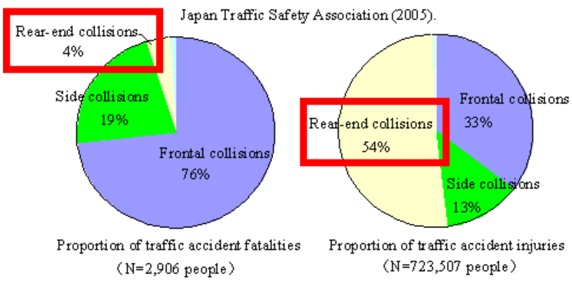

Figure 1. Proportion of Fatalities and Injuries per Location of Vehicle Damage.

In addition, a high proportion (77%) of rear-end collisions result in neck injury, most of which can be categorized as whiplash injury (Fig. 2).

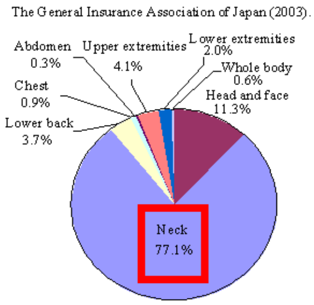

Figure 2. Proportion of Locations of Injury in Rear-End Collisions.

The primary cause of rear-end collisions is driver's poor attention to which caused by distraction ahead when driving, approximately 14% of accidents occur when the driver is looking forward but make's misjudgment by carelessness (Fig. 3).

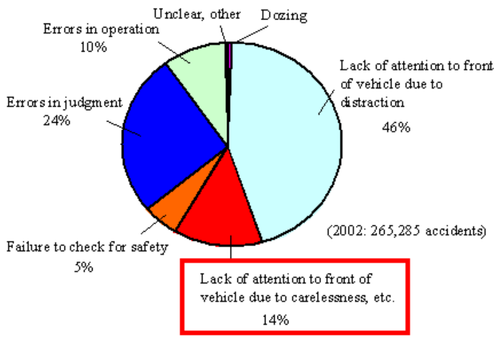

Figure 3. Causes of Rear-End Collisions Resulting in Fatality or Injury.

This figure suggests that providing some kind of warning to the driver of approaching vehicle from the rear would be an effective.
These facts provided the impetus for the development of the rear pre-crash safety system for rear-end collisions to lessen whiplash injury and reduce rear-end collisions itself.

Rear Pre-Crash Safety System

The pre-crash safety system for rear-end collisions consists of an obstacle detecting sensor, a control computer which judges a collision is impending or not, and actuators such as the hazard lights, headrests, and so on. The sensor is installed in the

rear bumper, and is made up of a version of the conventional frontal pre-crash safety system millimeter wave radar unit, which has been enhanced to enable short range monitoring of vehicles approaching from the rear.
The pre-crash computer controls the motion of pre-crash headrest which move forward to help reduce whiplash injury. The structure of the system is shown in Fig.4.

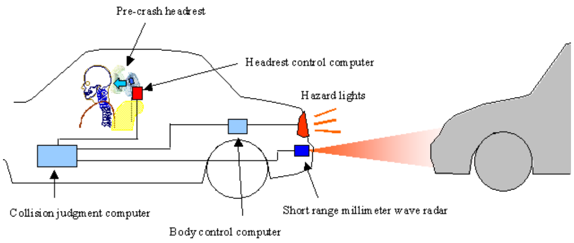

Figure 4. Structure of Pre-Crash Safety System for Rear-End Collisions.

Rear Short Range Millimeter Wave Radar – A compact millimeter wave radar which judge the possibility of rear-end collision has been developed as the sensor for detecting the risk of rear-end collision (Fig. 5).

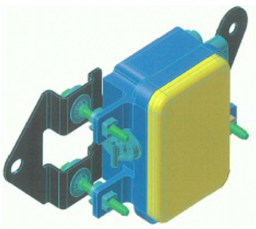

Figure 5. Rear Short Range Millimeter Wave Radar.

In general, the size of radar devices depends on the size of the antenna, and higher frequencies require smaller antennas. Since the size of the radar sensor is critical for installation in various types of vehicles, a high-frequency 76 GHz millimeter wave radar is adapted. This frequency has already been allocated for vehicle-installed radars throughout the world.
The types of objects to be detected are restricted to vehicles approaching from the rearward. Normally, vehicle radars for forward monitoring require sophisticated processing technology to distinguish stationary solid obstacles such as the road or objects on the roadside. However, rear-end collision detection can ignore such stationary solid obstacles, enabling simpler collision judgment than forward monitoring radars. For this reason, a less complex 3-channel electronic angle detection method was used for the circuit configuration, and the FM-CW method was used for the radar to achieve commonality with other radar devices. Table 1 shows the main radar specifications.

Table 1.
Main Radar Specifications

Item		Rear Short Range Millimeter Wave Radar	Frontal Millimeter Wave Radar
Radar system		FM-CW 3-channel electronic angle detection	FM-CW Electronic scanning
Center frequency		76.5 GHz	76.5 GHz
Detection performance	Distance	2~30 m	2~150 m
	Relative velocity	0~100 km/h	-200~+100 km/h
	Angle	+/- 15 deg	+/- 10 deg
Size		W67 × H88 × D47 mm	W107 × H77 × D53 mm

The locations where radar devices can be installed are restricted due to the effects of surrounding metallic objects on electrical waves. Installing the sensor inside the rear bumper prevents any part of the sensor from being exposed and has no adverse effects on the exterior vehicle design.
This rear millimeter wave radar detects the distance, relative velocity, and directional angle of vehicles approaching from the rear with an update cycle of approximately 20 msec, and transmits the detection data to the collision judgment computer via CAN communication.

Collision Judgment Computer – The collision judgment computer uses the detection data from the millimeter wave radar to calculate the estimated paths of vehicles approaching from the rear. This is then used as the basis to estimate the lateral time to collision (LTTC) after the estimated time to collision (TTC). TTC is calculated by dividing the distance to the vehicle approaching from the rear by the relative velocity. LTTC is obtained by monitoring time changes in the lateral position of the vehicle approaching from the rear and then calculating the lateral position after TTC by vector estimation.
In addition, because vehicles usually negotiate curves in set lanes, logic is employed to correct lateral position to follow the lane curvature. This curvature is calculated from the yaw rate or steering angle of the driver's vehicle (Fig. 6).

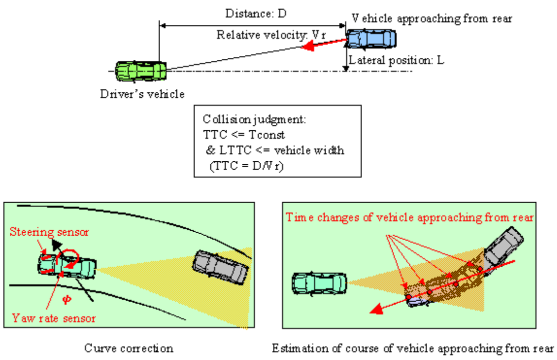

Figure 6. Rear-End Collision Judgment.

When the system judges that LTTC has almost passed through a range equal to the width of the driver's vehicle at a timing when the collision risk is high, it activates flashing of the hazard lights.
Additionally, judgment that LTTC has almost passed

through a range equal to the width of the driver's vehicle at a timing when a collision is unavoidable will also activates the pre-crash headrest.

Pre-Crash Hazard Lights – The hazard lights are flashed automatically as a warning to drivers of vehicles approaching from behind.
Once the collision judgment computer judges that there is a high risk of a rear-end collision, it transmits a signal to the body computer to activate automatic flashing of the hazard lights. The body computer uses this signal to flash the hazard lights for around 2 sec at a frequency of approximately 2 Hz (Fig. 7).

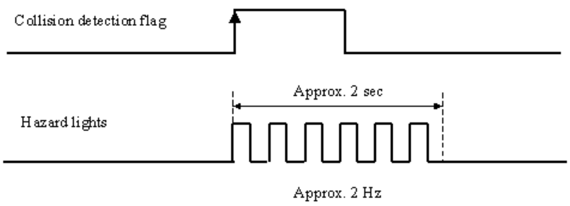

Figure 7. Pre-Crash Hazard Lights.

However, this system also gives priority to driver operation in the same way as other driver assistant systems. This means that automatic hazard light flashing is not activated when manual operation of the hazard lamps or turn signals is detected.
Additionally, in consideration of driver reaction time, warning approaching vehicles as early as possible is a more effective way of reducing rear-end collision speed. However, issuing needless warnings when drivers are already aware of the situation is irritating. Experiments showed that when there is the impending danger of a collision, drivers complete avoidance operations up to the period approximately 2 sec before the collision occurs.

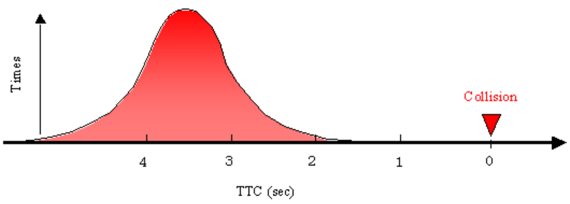

Figure 8. Avoidance Timing Distribution.

It is therefore highly likely that drivers would find warnings issued earlier than a TTC of 2 sec irritating. In response, the timing of hazard light flashing was set to a TTC of 1 to 2 sec.

Pre-Crash Headrest – Simultaneous restraint of the head and chest is regarded as the key to reducing whiplash injury.(1)(2) The pre-crash headrest system was developed to achieve this instantaneously when a rear-end collision is judged as unavoidable by moving the headrests forward toward the head of the occupant before the collision occurs.
When the collision judgment computer detects an unavoidable collision, it transmits a pre-crash headrest activation signal to the headrest control computer. Figs. 9 and 10 show the structure and electrical circuit configuration of the pre-crash headrest. Once the activation signal is received via CAN communication, a motor moves the headrest forward closer to the head of the occupant.

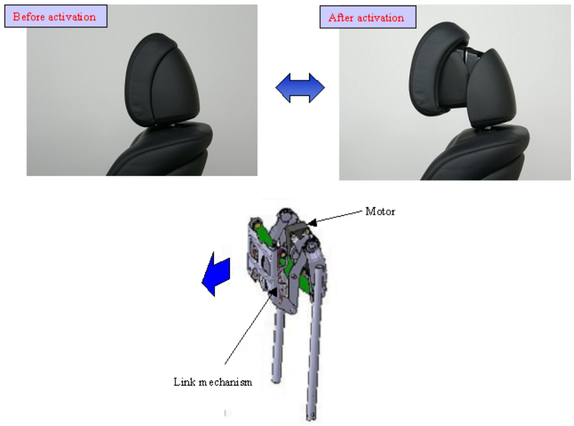

Figure 9. Pre-Crash Headrest.

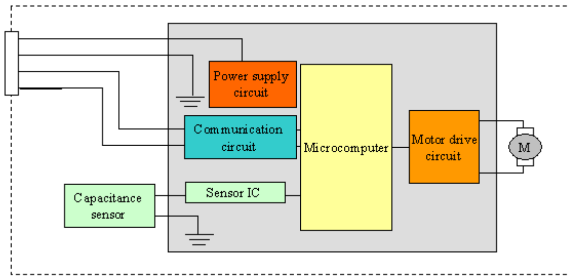

Figure 10. Electrical Circuit Configuration.

However, pushing the head more than necessary is only likely to worsen whiplash injury. The surface layer of the headrest therefore contains a head detection sensor, and utilizes a headrest position control mechanism.
This system uses changes in capacity as detected by the capacitance sensor when the headrest nears the head to stop the headrest immediately before contact. Fig. 11 shows the structure of the sensor. The headrest is programmed to move no more than approximately 60 mm in the forward direction.

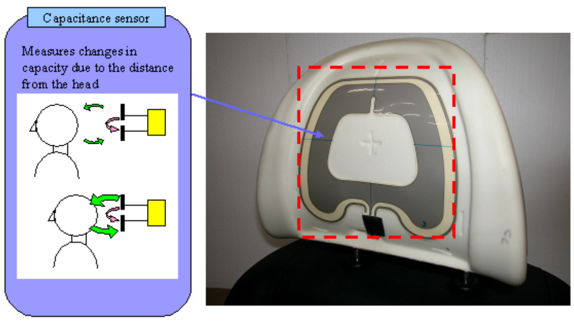

Figure 11. Head Detection Sensor.

In addition, because the motor can return the pre-crash headrest to the original position after it has been activated, it can be re-used without requiring repair in situations such as when the seat is unoccupied.

System Activation Timing – Fig. 12 shows the activation timing of the pre-crash hazard light and pre-crash headrest functions. The horizontal axis shows the time to rear-end collision.

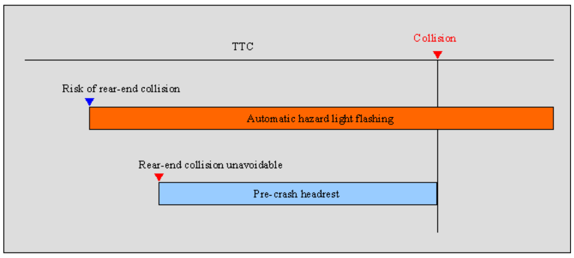

Figure 12. Activation Timing of Rear Pre-Crash Safety System for Rear-End Collisions.

Experimental Results and Effect

Actual Vehicle Test of Rear Radar – Fig. 13 shows detection data for vehicles approaching from the rear as measured during tests of the rear pre-crash safety system for rear-end collisions.

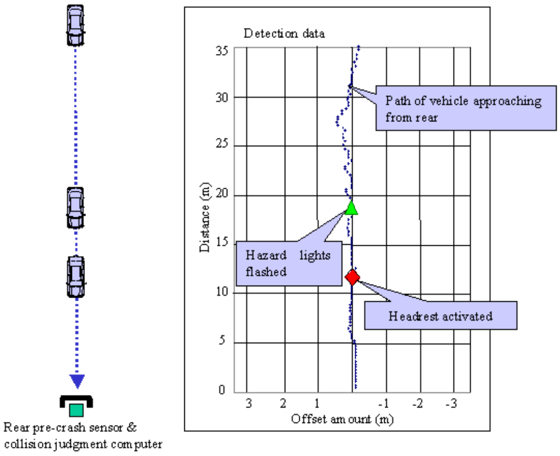

Figure 13. Actual Vehicle Experimental Data.

A vehicle was driven straight toward the pre-crash sensor at a constant speed of approximately 50 km/h. The graph shows the path of the vehicle as detected by the sensor, and the activation judgment timings for the pre-crash hazard light and pre-crash headrest functions. The test verified that the rear pre-crash sensor is capable of definitely detecting vehicles approaching from the rear.

Effect of Pre-Crash Hazard Lights – A test was performed to verify the effect of hazard light operation on the awareness of the driver in a following vehicle. Two vehicles were driven one behind the other at a speed of approximately 45 km/h and a following distance of approximately 18 m. The danger awareness reaction time (i.e., the time to brake pedal operation) of the driver in the following vehicle was then measured from the start of deceleration of the leading vehicle. It was verified that supplementing deceleration of the leading vehicle with automatic flashing of the hazard lights reduced the awareness time by approximately 20% from when the vehicle decelerated without flashing of the hazard lights (Fig. 14).

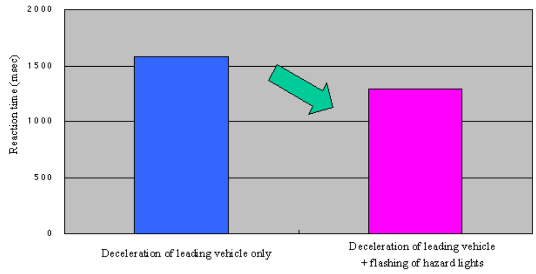

Figure 14. Reaction Time Comparison.

The effect when the vehicle equipped with the pre-crash hazard light function is stopped was obtained by calculation. The first case study in Fig. 15 examines a rear-end collision in which the vehicle approaching from the rear is traveling at approximately 60 km/h. In this case, when the provisional TTC is approximately 1.5 sec, the free running time is approximately 0.8 sec, and the vehicle approaching from the rear performs emergency braking of 6 m/sec^2, the driver is able to reduce vehicle speed to approximately 40 km/h at the point of collision. Under the same conditions, but with an approaching speed of approximately 30 km/h, the second case study in Fig. 15 shows that the driver is able to stop the vehicle before the collision occurs.

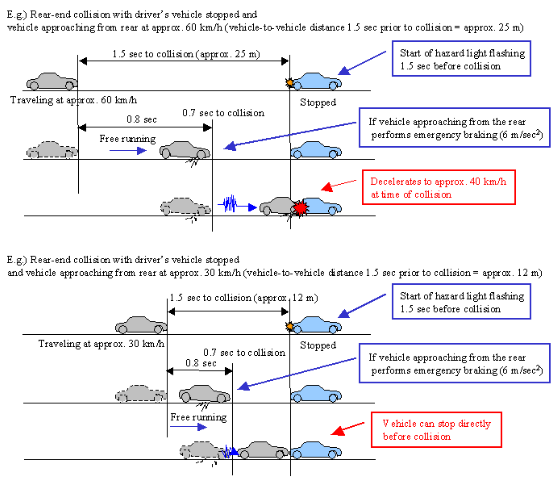

Figure 15. Case Studies.

Effect of Pre-Crash Headrest – A comparative evaluation with and without the pre-crash headrest was performed to verify its whiplash injury reduction effect. The test conditions followed the IIWPG protocol, and used a BioRID II dummy to measure the neck injury criteria (NIC) in a Δ V16 km/h impact sled test. The test verified that use of the pre-crash intelligent headrest reduced NIC by approximately 50%.

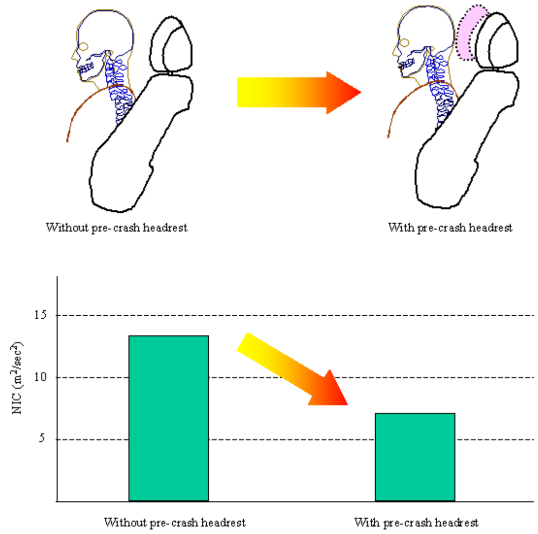

Figure 16. Whiplash Injury Evaluation.

CONCLUSIONS

A rear pre-crash safety system for rear-end collisions has been developed to lessen whiplash injury and reduce the number of rear-end collisions.
The newly developed system is able to lessen whiplash injury and reduce vehicle speed in rear-end collisions.

ACKNOWLEDGMENTS

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