RESEARCH OF BICYCLIST DETECTION BY ENHANCED PEDESTRIAN DETECTION SYSTEM WITH ADAS

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Paper Number 19-0251

ABSTRACT

Recent years have seen growing concern with bicyclists in terms of protection for vulnerable road users (VRU) [1]. One instance of this is the establishing of bicyclists to the Euro NCAP protocols for Automatic Emergency Braking (AEB) assessment.

In a real-world environment, however, even if AEB operates, there is still a possibility that the vehicle will not slow down sufficiently because of the timing of that operation, the vehicle environment, or the road surface environment. In this case, impact between the vehicle and the bicyclist may occur.

Consequently, there remains a necessity for technology to detect impact with bicyclists.

For this paper, the investigation was carried out with a focus on the detection of bicyclist impact in two modes. They are run-out mode and rear-end impact mode, in which detection is assumed to present a challenge because the bicyclist and the vehicle bumper do not come into contact.

As a method for detecting impact with a bicyclist in the above modes, a detection system was devised that integrates a conventional pedestrian detection system, deformation sensors mounted around the bumper surface periphery, and ADAS information. This will be referred to as the integrated impact detection system.

Bumper surface deformation sensors are used to detect minute deformations of the bumper surface caused by a bicycle. ADAS information is used to control the threshold for impact judgment. The conventional pedestrian detection system is used mainly to detect the impact of a bicyclist near the central portion of the vehicle.

We conducted CBU tests and simulations on the integrated impact detection system we invented this time and confirmed and investigated the bicyclist impact detection performance.

As a result, it was found that minute inputs to the bumper surface caused by a bicycle can be effectively detected by the deformation sensors. The deformation sensors alone are sensitive to inputs to the bumper surface. However, the reliability of impact detection can be maintained by using ADAS information to control the deformation sensor threshold when operation of the vulnerable road user protection device is required. Incorporating the conventional pedestrian detection system into this system also maintains reliability.

It was determined from these results that the combination of the conventional pedestrian detection system, deformation sensors, and ADAS information in an integrated impact detection system presented possibilities for detection of impact with bicyclists in run-out and rear-end impact modes.

INTRODUCTION

Bicyclist protection has been established to the Euro NCAP protocols for AEB assessment. However, AEB functionality is determined by the vehicle environment, the road surface environment, weather conditions, and other such factors. Some possibility remains, therefore, that even if the AEB operates, it will not slow the vehicle sufficiently and that impact of the vehicle with a bicyclist could occur. Consequently, there is still a necessity for technology to detect impact with bicyclists.

For this paper, therefore, the detection of bicyclist impact was investigated with a focus on impact detection in rear-end impact mode and in run-out mode, when detection is considered to be a challenge because bicyclists themselves do not contact with the vehicle bumper.

As a method of VRU impact detection, it is well known that is used acceleration sensor or pressure sensor located around bumper beam for pedestrian impact detection [2][3]. The purpose of these sensors is to detect the input to the bumper beam caused by pedestrian impact. This presupposes that the impacting object penetrates up to the bumper beam.

When the input to pedestrian detection system sensors is small, the system will determine that the situation does not necessitate operation of a pop-up hood (PUH [4]) or other such pedestrian protection device. That is, the system will determine that no pedestrian impact has occurred or that impact was in a speed range that does not require a device. In other words, when the impacting object does not penetrate up to the bumper beam, the sensors will not detect and pedestrian protection devices will not operate.

In the case of run-out mode or rear-end impact mode, only the front wheel or rear wheel of the bicycle contacts the bumper. Since the bicyclists themselves do not contact the bumper, penetration up to the bumper beam does not occur.

However, bicyclists move at higher initial speeds than pedestrians. When impact occurs, therefore, there may be impact with the vehicle body due to the inertia of the bicyclist, as in Fig. 1, even if the input to the bumper beam is insufficient. It is therefore necessary to have impact detection that will cause protective devices (in this case, e.g., the A pillar airbag) to operate.

Because of the reason mentioned above, the investigation was carried out with a view to detecting impact and causing protective devices to operate even when penetration by bicyclists does not reach up to the bumper beam.

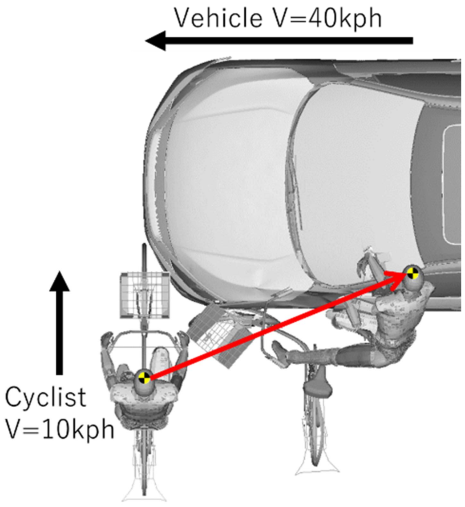


Figure 1. Post-impact behavior of run-out bicyclists

PURPOSE

The purpose is to enhance performance of the conventional pedestrian detection system so that the system will detect the bicyclist in the case of bicyclist impact that does not penetrate up to the bumper beam.

ACHIEVEMENT METHOD

Method of detecting bicyclists

Bicyclists themselves do not contact with the vehicle bumper in run-out mode or rear-end impact mode, but minute deformations of the bumper surface are caused by the bicycle. Consequently, the approach here will be based on configuration of G sensors (hereafter surface-G sensors) on the rear side of the bumper surface as deformation sensors, and these surface-G sensors are added to the pedestrian detection system.

The use of surface-G sensors makes it possible to react to low-input impact modes that only contact with the bicycle front wheel or rear wheel. On the other hand, it is possible that VRU protection devices would operate when impact with something other than a person (such as a road pylon) occurs.

Therefore, we devised integrated safety system using ADAS radar and camera, the ego-vehicle speed, and the relative speed with bicycle, angle. This is used to judge whether impact with a bicyclist is unavoidable, and only when it is judged unavoidable will the impact judgment threshold of the surface-G sensor be lowered to make the system reach an impact judgment. In the case where the impact is escaped by the avoidance behavior of the bicyclist or the vehicle, the threshold is restored to the normal time.

With regard to impact with the central portion of the vehicle when the bicyclist and the vehicle bumper contact, we decided to have the conventional pedestrian detection system make the impact judgment.

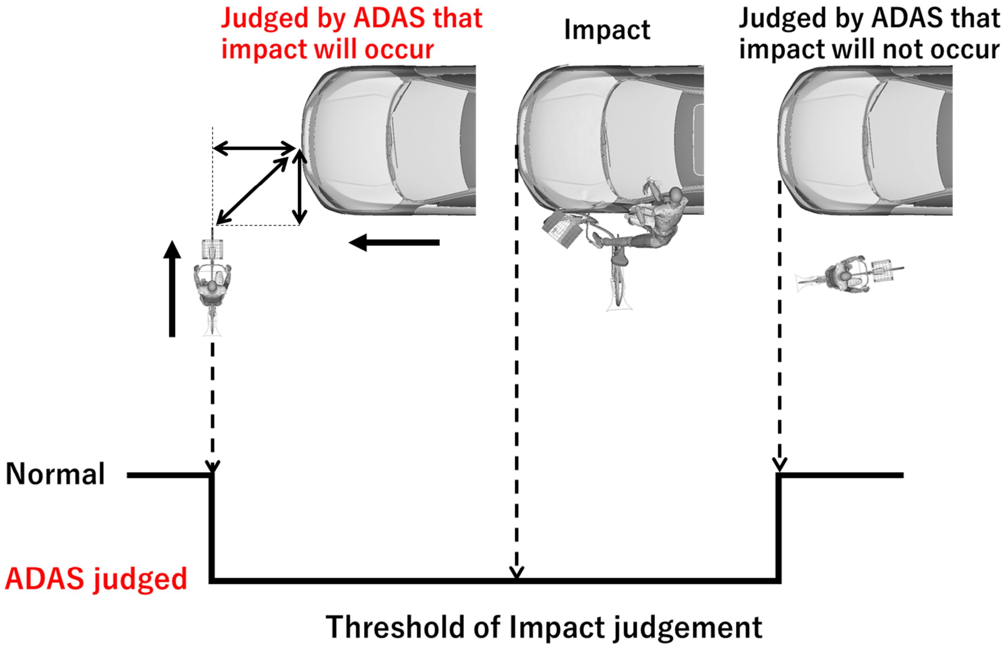


Figure 2. Threshold control by ADAS coordination

Detection algorithm

Only bicyclists are defined as objects that should be detected by means of ADAS. If the system were set to detect objects other than bicyclists and treat them as integrated detection system control objects, the number of such objects would become very large and reliability would be reduced. It was therefore decided to lower the surface-G sensor threshold only when impact with bicyclists is anticipated.

The surface-G sensor threshold is basically set, as the pedestrian detection threshold is set, as shown in Fig. 3, so that the reaction to impact with objects other than bicyclists and the misuse mode about driving on rough roads and other such conditions will both be turned OFF. However, we decided that when the integrated detection system uses ADAS information to control the threshold, the threshold level will be lowered to where the above misuse mode is turned OFF.

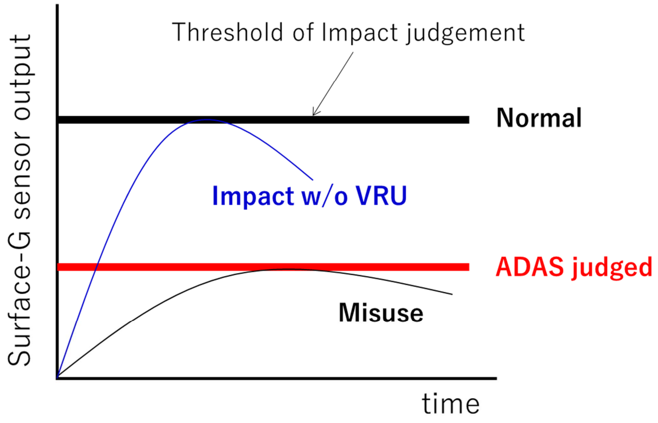


Figure 3. Conceptual approach to setting the threshold

One or two surface-G sensors each are mounted at the left and right sides of the bumper surface. Surface-G sensors on the left side react to impacts on the left side, and surface-G sensors on the right side react to impacts on the right side. As shown in Fig. 4, a VRU protection device will be deployed when judgment is made by pedestrian detection system sensors or by the integrated impact detection system.

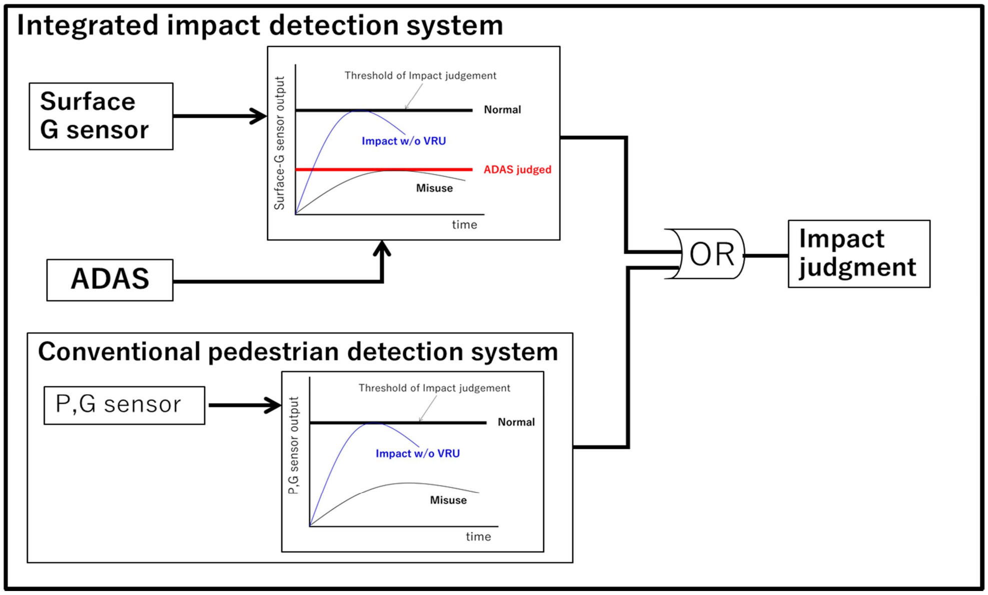


Figure 4. Bicyclist impact detection algorithm

VERIFICATION METHOD

We verified the performance about cyclist detection using Surface-G sensor of integrated impact detection system by CBU impact test and simulation. CBU test and simulation configuration will be described here.

The vehicle was middle class sedan, the bicycle was Citybike-type and the cyclist was POLAR2 dummy [5] which was a pedestrian dummy developed by Honda. The vehicle speed was set at 25 km/h. Vehicle speed at 25 km/h is same as lower limit speed to deploy the PUH. This is based on the thinking that the impact upper limit speed at which pedestrian's HIC become to or below the regulatory standard value when PUH does not deploy is about 25 km/h.

Figure 5 shows a result of simulation in the bicyclist impact with vehicle speed at 25 km/h. Since even in the bicyclist, the head contact with the hood at an impact with a vehicle speed at 25 km / h, we predicted that HIC would be equivalent to pedestrians. Therefore, we decided to proceed with the performance verification with the impact detection lower limit speed for bicyclist detection set at 25 km/h. As for the run-out mode, as shown in Fig. 1, since The bicyclist contacts with the vehicle at a vehicle speed at 40 km/h, we predicted that it will occur even at 25 km/h.

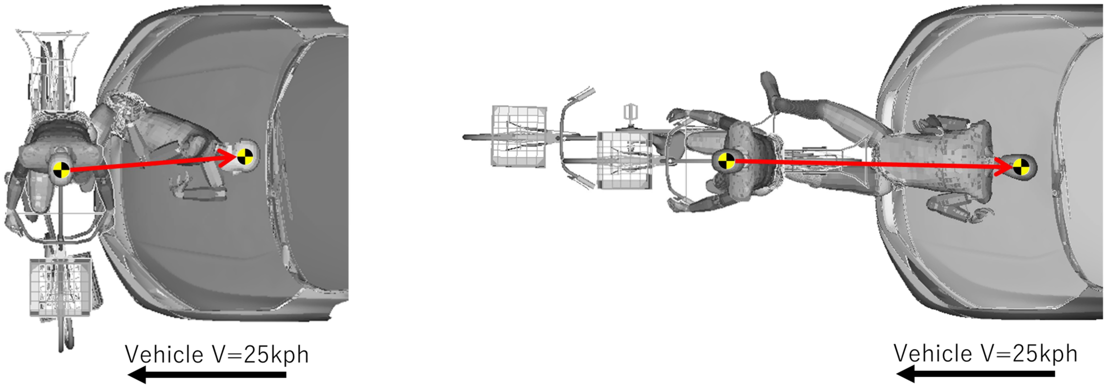


Figure 5. Post-impact behavior of bicyclists at 25 km/h

Test was also carried out in run-out mode with a stationary bicyclist. Because both pedestrian sensors and surface-G sensors primarily detect input in the direction of the vehicle's forward movement (the x axis), and it has little influence on the performance of detection as to whether or not there is input in the direction of the bicyclist's movement (the y axis), and in order to keep the CBU test simple and to heighten reproducibility during continuing investigation.

The vehicle was configured with pressure sensors on the front of the bumper beam as a conventional pedestrian detection system. For the integrated detection system, surface-G sensors were mounted at 100-mm interval length from the vehicle center on the back of the bumper surface.

Impact Mode

The impact modes for verification were configured as the run-out impact mode, rear-end impact mode, and vehicle center impact mode.

Run-out impact mode (impact at end of vehicle): The collision location in run-out impact mode was defined as shown in Fig. 6, as the mode where the vehicle and bicycle overlap by 450 mm. When impact occurs with the vehicle speed at 25 km/h and bicycle speed at 10 km/h, the lower limit for the overlap length where the bicyclist impacts the vehicle is 450 mm (simulation result). When the overlap length is lower than this, the effectiveness of the VRU protection device will be diminished. Therefore, 450 mm was set as the lower limit for overlap length at which impact detection becomes necessary.

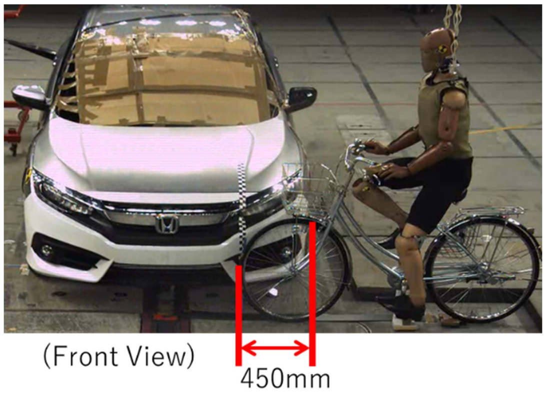


Figure 6. Setting of overlap length of run-out bicyclist and vehicle

Rear-end impact mode: In rear-end impact mode, the behavior will be the same no matter where along the lateral direction of the vehicle is contact. Bicyclists will move toward the vehicle and contact with the vehicle no matter where they contact the vehicle. In light of the above, we decided the IP in rear-end impact mode was set as the vehicle center, as shown in Fig. 7. Furthermore, the contact with the bumper is only for the thickness of the bicycle rear wheel. Therefore, input will occur along a narrower range in the lateral direction than in run-out mode. So the area at which rear-end impact detection becomes necessary becomes almost the whole area in the vehicle width direction. Emplacement of multiple surface-G sensors would enable reaction to any collision location, however this would increase the cost.

In other words, the length in the lateral direction over which a single surface-G sensor is capable of detection is a key point for rear-end impact detection. Verification was therefore carried out from that perspective.

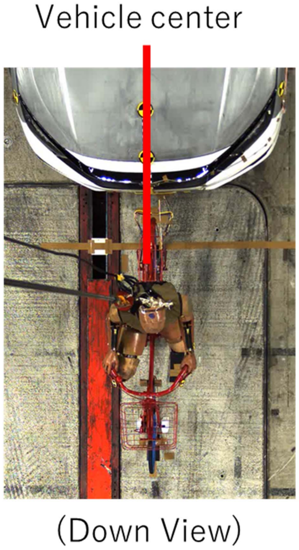


Figure 7. Rear-end impact mode

Impact mode for the central portion of the vehicle: For impact mode for the central portion of the vehicle in which the bicyclist and the vehicle contact, it is envisioned that impact detection will be implemented by the conventional pedestrian detection system. In order for impact judgment to be made from pedestrian sensors, an object of sufficient mass should penetrate to the front of the bumper beam so that input is applied to the sensors. Impact is typically detected from the leg mass of a pedestrian. Consequently, the key point for detection of bicyclists using the pedestrian sensors is relationship of overlap length of the bumper beam and the leg.

When impact occurs between a pedestrian and a vehicle, ordinarily two legs contact with the vehicle at bumper beam height. This applies input to sensors at the front of the bumper beam.

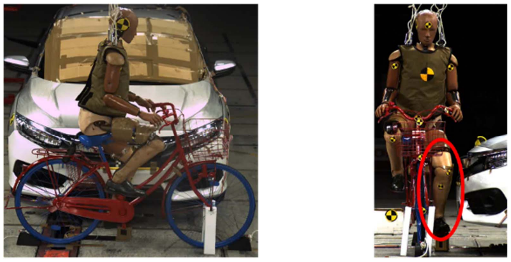
On the other hand, when bicyclists pedal a bicycle, their legs move in up and down strokes. Depending on the position of the pedals, therefore, it is possible that only the mass equivalent to one leg will actually provide input to the sensors.

That state was considered to be the worst case in terms of impact detection. The present CBU testing was therefore carried out with the mode in which the pedal is at the topmost position (this will be termed top-dead-center mode) and the mode in which the pedal is at the bottommost position (this will be termed bottom-dead-center mode) taken as the worst-case conditions.

Top dead center

(Front View) (Side View)

Bottom dead center



(Front View) (Side View)

Figure8. Top-dead-center mode and bottom-dead-center mode

RESULTS

Run-out impact mode (impact at end of vehicle)

Figure 9 shows a map of surface-G sensor output in an impact with 450mm overlap. We plotted the impact without VRU (hereafter Light weight object) and the misuse-mode without Light weight object (hereafter Misuse) as the mode in which thresholds intended to keep OFF, and configured two thresholds.

The black line is the threshold at which the judgment by ADAS predicting impact will be OFF. This was configured so that both Light weight object and Misuse would be OFF.

The red line is the threshold at which the judgment by ADAS predicting impact will be ON. This was configured to turn Misuse OFF. This is based on the basic concept that the system should turn Misuse OFF even if the integrated detection system lowers the threshold according to ADAS information.

The vertical axis of the map shows the definite integral value (km/h) of the surface-G sensor. The horizontal axis shows the stroke of the surface-G sensor. The impact causes G to be generated in a short time, while the Misuse like rough road-mode tend to generate G over a long time. Therefore, mapping it enables a grasp of the distinctive characteristics of an impact.

According to the map, run-out bicyclist reaches the threshold ADAS judged, but it largely does not reach the normal threshold.

When compared between impact phenomena, it can be a challenge to differentiate those that are in OFF mode (IP is directly above the sensor) that have high-level sensor outputs and run-out bicyclists that have low-level sensor outputs. This further clarifies the necessity for using ADAS information so that the surface-G sensor threshold can be lowered.

It was apparent from these results that in run-out impact mode, it is effective to use the method of controlling the threshold of surface-G sensors located on the bumper surface by means of ADAS information so that they will be turned ON.

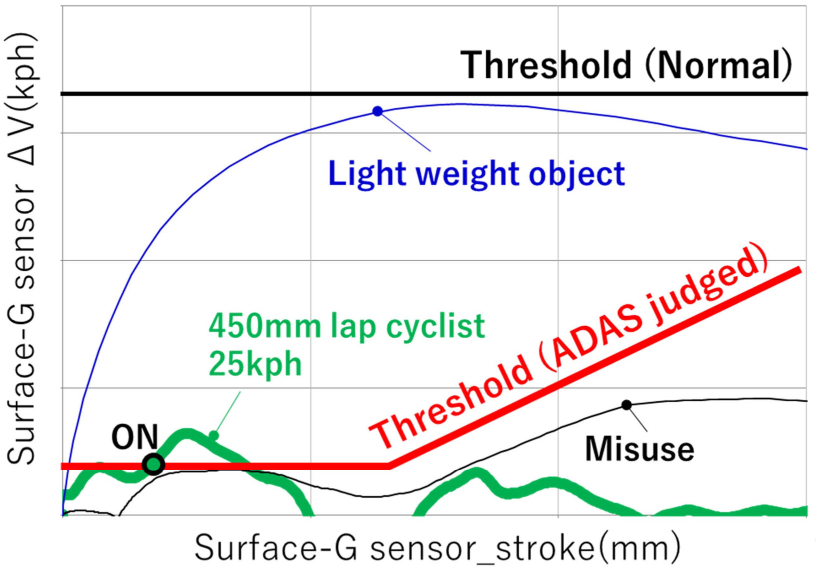


Figure 9. Detection of bicyclist by surface-G sensor (Run-out mode impact)

Rear-end impact mode
Figure 10 shows the results for outputs from surface-G sensors placed at 100mm intervals on the back of the bumper surface, with rear-end impact at the vehicle center when the vehicle speed is 25 km/h.

The largest output comes from the central sensor. The sensitivity decreases as the distance from the center increases, and it was found that outputs at levels exceeding the threshold for turning misuse OFF were obtained from sensors located up to 400 mm away from the center.

However, since the tendency toward lower outputs increased between 300 mm and 400 mm, we considered appropriate to define the location of the surface-G sensor ±300 mm as the area where detection is certain.

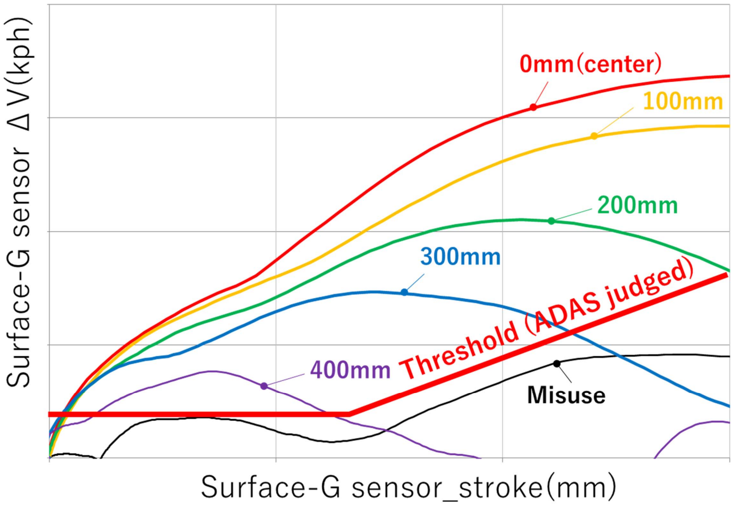


Figure 10. Surface-G sensor sensitivity in rear-end impact detection

Impact mode for the central portion of the vehicle

Figure 11 shows pedestrian sensor outputs at top-dead-center and bottom-dead-center.

At the initial time of impact (up to around 20 ms), sensor outputs are generated due to inputs from the leg on the impact side. However, they are not able to exceed the threshold level since almost all of the bicyclist's weight is on the bicycle saddle and the leg is in a state close to free flight, so that the input to the bumper beam is small.

From around 30 ms, there is additional input generated by the bicycle itself. With inputs from the leg on the impact side together with the bicycle, sensor outputs are generated at a level exceeding the threshold. It is apparent that from around 40 ms, input from the leg on the non-impact side is causing a further increase in sensor output.

It was found from these results that with impact at the central portion of the vehicle, the conventional pedestrian detection system is effective.

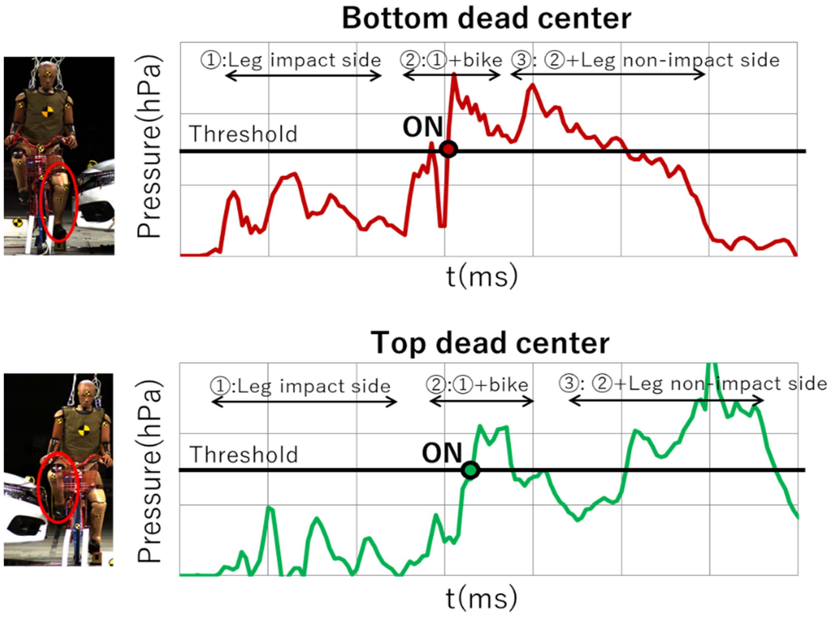


Figure 11. Bicyclist detection by pedestrian sensor (Impact at central portion of the vehicle)

DISCUSSION

Verification of number of surface-G sensors

Figure 12 shows run-out mode (simulation) results for every overlap length. Red portions of the contour indicate the regions where the integrated detection system can detect. Detection is most demanding at 450 mm, the bottom limit for overlap length at which device operation is required. That is because the front wheel that makes initial contact and the bumper are in a mode close to point contact due to the styling camber curve. As the overlap length increases, the front wheel and bumper approach surface-to-surface contact so that inputs to the surface-G sensors also increase, making detection easier. When the overlap reaches or exceeds 1050 mm, the system becomes able to react with the surface-G sensor on the bicyclist's leg or its opposite side (in the case of left side run-out, on the right side).

It was apparent from these results that run-out mode, including 450-mm overlap mode where detection is most challenging, could be fully covered when surface-G sensors are placed at locations near the center with each one for right and left.

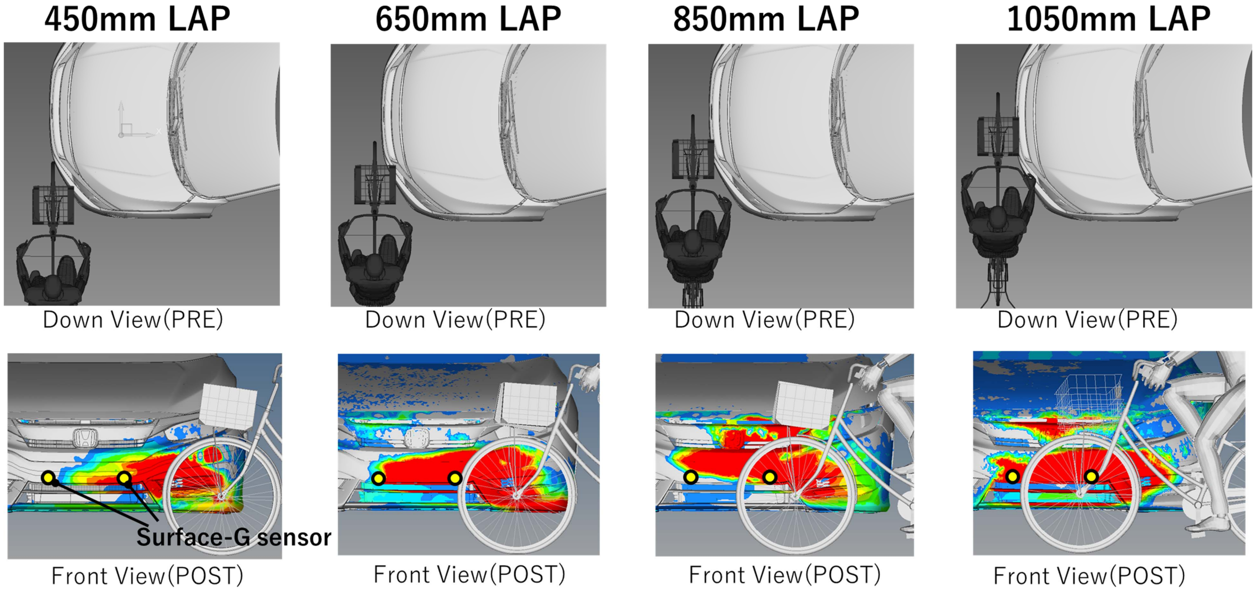


Figure 12. Inputs to surface-G sensors at different overlap length (simulation)

In the rear-end impact mode described above, the detection sensitivity of the surface-G sensor was ±300 mm. It is difficult to detect the Rear end impact of vehicle outside end using surface-G sensor for Run out mode.

Therefore, in order to detect both modes, it was found that multiple sensors were necessary in consideration of sensitivity as shown in Fig.13.

This paper describes results of investigation using a middle class sedan. If the styling design of the vehicle changes, then the input to the surface-G sensors will also change. In the case of styling design that involves a larger camber angle, in particular, and if the impact overlap is small, then it is possible that the bumper input from the bicycle front wheel will not reach all the way to the surface-G sensors.

In that case, we are thinking that is to enhance detection performance either by configuring G-transmission components behind the bumper surface in order to increase the rigidity around the surface-G sensors or by adding more surface-G sensors.

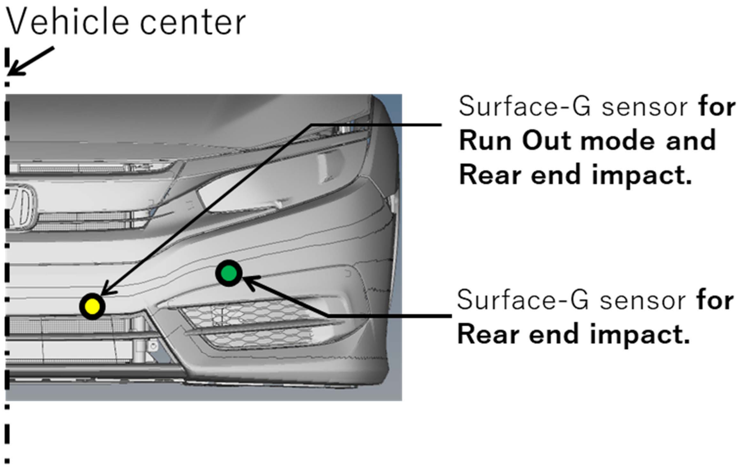


Figure 13. Surface-G sensor arrangement concept

CONCLUSIONS

In this paper, we devised the system for impact detection in bicyclist run-out and rear-end impact modes, which generate very small inputs, by adding surface-G sensors to a conventional pedestrian detection system and verified the performance of the resulting system by CBU impact test and simulation.

It was confirmed that bicyclists could be detected in run-out and rear-end impact modes by controlling surface-G sensor thresholds by means of coordination with ADAS. It was also confirmed that the conventional pedestrian detection system was effective for impacts with the central portion of the vehicle.

It was determined that an integrated impact detection system using a conventional pedestrian detection system with enhanced performance has possibilities for detection of bicyclist impact.

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