Side Crash Detection Using Vehicle Behavior Change

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ABSTRACT

The conventional detection method of a side crash is using either a pressure sensor located on the door or an acceleration sensor, also referred to as G sensor. These sensors detect body intrusion in a side crash.

This paper focused not only on intrusion of body but also on vehicle behavior change, which is detected simultaneously with body intrusion in a side crash. Using intrusion and behavior change of vehicle, an investigation of side crash detection performance was conducted.

Two methods were devised to detect vehicle behavior change in a side crash. One method is using yaw-rate sensor located at the center of the vehicle, and the second method is using a G sensor, which has a sensitivity axis in the longitudinal direction of the vehicle and located on the body side.

A side crash detection algorithm was also devised which combined G sensor of lateral direction, which detects lateral accelerations in a side crash, and a yaw-rate sensor or G sensor of longitudinal vehicle direction, which detects other changes to the impacted vehicle other than lateral accelerations, referred to in this study as vehicle behavior.

This research sought to determine whether crash detection performance can be satisfied for various crash modes using numerical simulations.

The results of these numerical simulations indicate that G sensor response time is fast which makes it effective in detecting a high speed crash. The results also showed that yaw-rate data is stable, which implies that data is reliable, allowing the use of the developed crash detection algorithm for predicting vehicle behavior changes, within certain speed limits.

Moreover, a side crash test using a test vehicle, also referred to in this paper as Complete Body Unit or CBU, CBU was also completed and confirmed that body intrusion and vehicle behavior change occur simultaneously and can be reasonably detected a side crash using this paper’s crash detection algorithm. This could potentially transform side crash detection in the automotive industry.

INTRODUCTION

The conventional method of detecting impact forces during a side crash is using an accelerometer or a pressure sensor [1] [2]. Accelerometers detect velocity changes while pressure sensors detect door cavity volume changes which indicate a body intrusion in a crash. These methods are effective only when the impact directly hits the sensors. Such limitation requires either the strategic placement of sensors or the use of multiple ones in a vehicle. The latter would increase the complexity of car development and would increase costs.

To avoid both development complexity and cost increases, as well as to attain a more inclusive analysis of side crash investigations, the research focused on overall vehicle motion changes during an impact, which is referred to in this research as “vehicle behavior change.”

The purpose of this research is whether crash detection using vehicle behavior change is possible.

In the case of a side crash, when the impact point is near the vehicle’s center of gravity (COG), the energy is absorbed mainly by body deformation and there is little vehicle behavior change. But when a crash point is farther from the vehicle’s center of gravity (For example, in a vehicle of FF layout, in the case of a second row side pole impact), vehicle behavior change occurs simultaneously with body intrusion.

Accelerators and pressure sensors are effective in detecting a side crash when the impact is near COG. However, when the impact is away from COG, it may be useful to deploy a system that can calculate vehicle behavior change. Vehicle behavior change is a physical quantity that can be calculated from crash velocity and can be theoretically used for detecting occurrence of crashes.

METHODOLOGY

Principle of detection

Figure 1 and Figure 2 indicate a difference of vehicle behavior changes due to a difference in crash speeds with nearly the same crash point at the second row.

Figure 1 show the situation at 150 msec. of the CBU test where the pole collides with second row side at low speed and middle speed.

Low speed is a crash speed in which the side curtain airbag should not deploy. The middle speed is a crash speed in which the side curtain airbag must deploy.

The picture on the left side of Figure 1 show that at the low speed crash, energy is absorbed by the deformation of the vehicle’s body and there is insignificant post-impact vehicle velocity change. On the other hand, the right side of Figure 1 show that energy was not absorbed by body deformation and there is considerable post-impact vehicle velocity changes or vehicle behavior change.

Figure 2 illustrates middle speed and high speed side pole crashes. Both speeds require the deployment of the side curtain airbag. The picture indicates that there is considerable vehicle behavior change. Furthermore, the picture shows that vehicle behavior change is more apparent in the high speed crash than in the middle speed crash.

It was observed that there is insignificant vehicle behavior change at low speed crashes. However, at crash speeds that required side curtain airbag deployment, vehicle behavior changes are observable and can be calculated as a physical quantity. This physical quantity can be used for crash detection.

Figure 3 shows a middle speed pole crash at 150 msec. after impact. The picture on the left in Figure 3 shows the pole crashing into the first row side. This impact point is close to the center of gravity of the vehicle. Energy is mainly absorbed by the deformation of the body and vehicle behavior change is again, insignificant. In this case, accelerometers and pressure sensors can easily detect body intrusion. It is not necessary to use vehicle behavior change for crash with impact points that are close to the vehicle’s center of gravity. The picture on the right of Figure 3, show the impact at the second row side of the vehicle and far from the center of gravity. The picture also show that there is both intrusion of body and vehicle behavior change (Yaw of vehicle) occurring simultaneously at 150 msec. after impact. There is a significant vehicle behavior change, which can be quantified and can be used as an indicator of a crash.

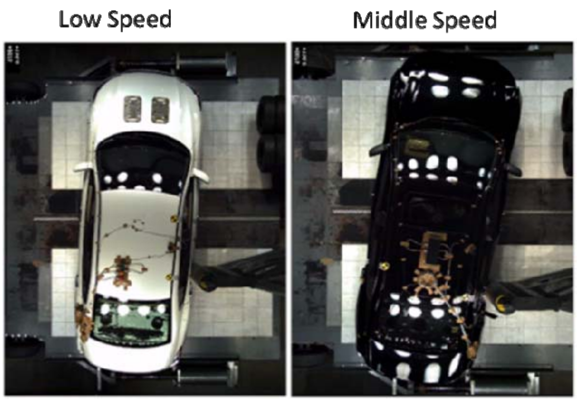

Figure 1. Vehicle positions at 150 msec. after impact for low and middle speeds.

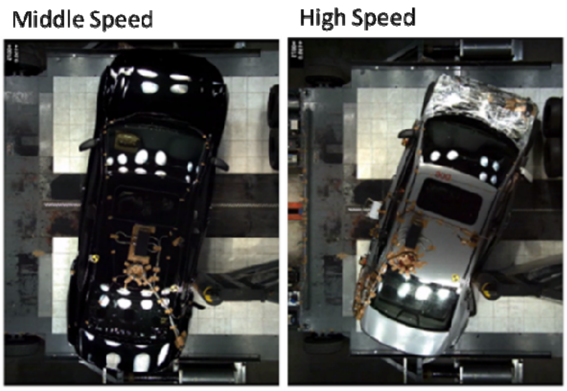

Figure 2. Vehicle positions at 150msec. after impact for middle and high speeds.

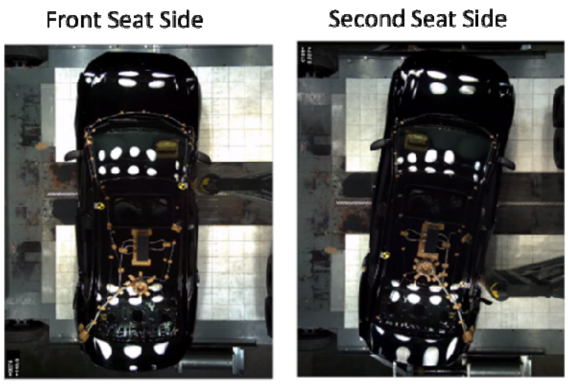

Figure 3. Vehicle positions at 150msec. after impact for front and second row side crashes.

Detection methods of vehicle behavior change.

Two methods were devised as detection methods of vehicle behavior change during a side crash beside second seat.

One method is to detect vehicle yaw-rate directly using a yaw-rate sensor.

Since a vehicle has inertia, when vehicle behavior change will once occur, data of yaw-rate is stable. So we expected that performance of crash detection has stability.

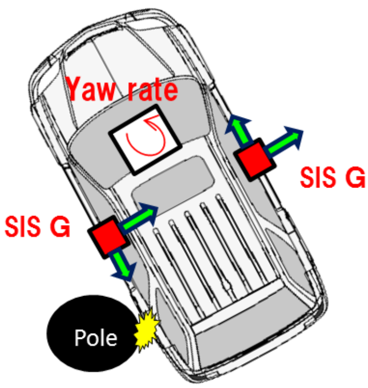

Figure 4. Detection direction of each sensor at a time of a side pole crash.

For example, when a side pole crash occurs near a second seat, a yaw-rate sensor detects yaw-rate in counterclockwise direction as shown in Figure 4.

Another method is using a satellite G sensor which has a sensitivity axis of vehicle longitudinal direction. The satellite G sensor is located on body side. This sensor is called a satellite impact sensor and is abbreviated as SIS in this paper.

For example, when a side pole crash occurs near a second seat, SIS detects G which direction is indicated with green arrows in Figure 4.

How to use the two detection methods

The characteristics of data are different between G and yaw-rate sensors. So we use two methods.

Since G is transmitted along a body member during a crash, there is a characteristic that the response is fast. Therefore, it seems that it is suitable for a high speed crash. Because a high speed crash requires a fast response time.

The response of the yaw-rate sensor is not as fast as the accelerometer but it is stable which makes it suitable for detecting middle speed impacts.

The characteristics of the yaw-rate data are shown by CBU test data in Figure 5.

The CBU test data of a side pole crash into the second row at middle speed is the data shown in Figure 5.

In this paper, in a case of a high speed side crash, we use accelerometer sensor data for detection of vehicle behavior change as we expect fast response and in a case of a middle speed side crash we use data of yaw-rate sensor to detect of vehicle behavior change as we expect a stable response.

In this paper, a timing of side crash detection for establishing passenger protection performance is hereinafter referred to as T-TTF (Target Time to fire) and we researched whether the sensing system can detect the crash at the desired T-TTF.

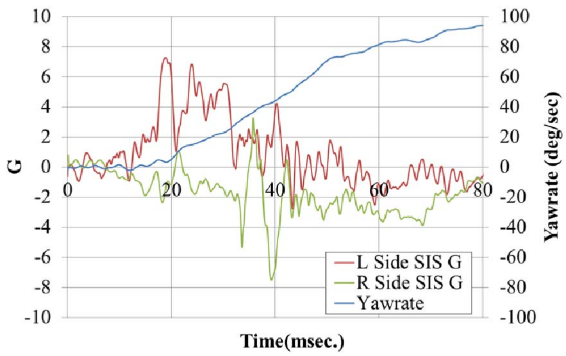

Figure 5. Data of each sensor at middle speed crash.

Layout of sensors used for this research

Since the behavior of the entire vehicle changes during a side crash event the area that can be utilized for sensor application is large. We aimed at a simple sensor system. So, we tried to integrate as much as possible with a conventional sensor system. For that reason, we have conducted this study based on a simple sensor system shown in Figure 6 and Figure 7.

Yaw-rate sensor data was acquired at the SRS-unit located on the front floor. Detection of vehicle behavior change by acceleration used a sensor located on B-PLR LWR as shown in Figure 6 and 7.

Conventionally, in order to detect vehicle acceleration, this sensor has a sensitivity axis in lateral direction of vehicle. In this study, the sensor also detects vehicle behavior change, this sensor also incorporates an accelerometer in the longitudinal direction.

In this paper, X, Y, Z coordinates are defined as shown in Figure 7. Longitudinal direction of a vehicle is X, lateral direction is Y, and vertical direction is Z. In addition, when it is written as Gy, it indicates that it is G in the vehicle Y direction and when it is written as Gx, it indicates that it is G in the vehicle X direction.

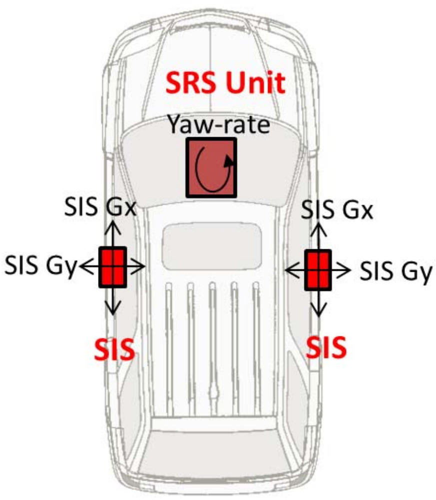

Figure 6. Sensor layout.

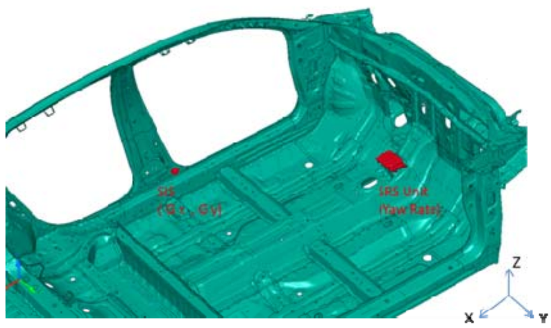

Figure 7. Sensor layout.

Crash detection algorithm

In a pole crash impacting the second row, there are two features as explained.

One is that G and yaw-rate sensors respond for a short time. Another is that Gy data and Gx and yaw-rate data related to vehicle motion change respond are available at the same time.

An algorithm to detect these features is needed.

We devised a crash detection algorithm based on a two-dimensional map of vehicle motion change. This algorithm shows features which body intrusion and vehicle behavior change occur. The two-dimensional map which we devised is as shown in Figure 8. In this algorithm, the horizontal axis is a value calculated based on data of yaw-rate sensor or SIS Gx. The vertical axis is a value calculated based on data of SIS Gy. Crash detection is carried out based on a path of these data on this map.

In order to capturing features of the crash data occur over very short time duration we focus on a point which a value is calculated based on yaw-rate and G.

In order to capture a short time event, it is effective to use a difference value of about several tens of msec. for yaw-rate sensor data and a definite integral value of about several tens of msec. for G data. By looking at these data for a certain time in this way, these data becomes large in a short duration event and small in a long duration event. This makes it possible to easily separate a crash event from a misuse event during normal driving.

For a certain time of several tens of msec. optimum value differs depending on body, so adjustment is required depending on body.

In this paper, in a case of high speed crash, a definite integral value of SIS Gy is used as the vertical axis and a definite integral value of SIS Gx is used on the horizontal axis. In a middle speed crash, a difference value of SIS Gy is used on the vertical axis and a difference value of yaw-rate sensor is used on the horizontal axis. We investigated crash detection performance using these physical quantities in the algorithm.

In the map of this algorithm, intrusion of body and vehicle behavior change also come out as a physical quantity corresponding to crash speed, so that distance from the origin has a meaning corresponding to crash speed.

We do not want to deploy airbag in case of a low speed crash and want to deploy it in case of a middle speed or more. Therefore, by setting a threshold value to be larger than data of a low speed crash, it is possible to make a judgment that airbag is not deployed, because it does not exceed a threshold value in case of a low speed crash. Since data exceeds a threshold value in case of a middle speed crash or more, it is possible to make a judgment to deploy airbag.

Also, when a side crash occurs near center of gravity of vehicle (for example, crash of front seat side), intrusion due to crash comes out large and vehicle behavior change is small, so a value on the horizontal axis is small and a value on the vertical axis is large. So a path of the data on the map of algorithm extends for upward shown as Figure 8. On the contrary, when a crash occurs at far from center of gravity of vehicle, intrusion and behavior come out, so that a path of the data on the map of algorithm extends for diagonally upward. Approximate crash position can be estimated by a direction of the data.

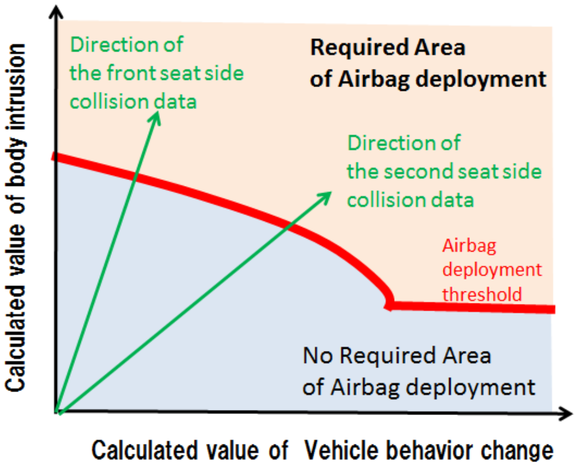

Figure 8. Crash detection algorithm using two-dimensional map.

RESULTS

Verification on various crashes using simulation

For various crashes, we confirmed whether the algorithm we devised can be possible to respond.

Simulation used LS-DYNA as a solver and used a model correlated with CBU test. It was verified with a model based on Honda Accord.

The verified modes are as shown in table.1. In this time, we selected modes which pole impacts the second row side.

We verified by changing diameter of pole, crash speed, crash angle and crash position.

The crash angle is as shown in Figure 9.

The crash position is as shown in Figure 10, and the second seat side is defined as mid. Front and mid, mid and rear have a distance of 400 mm.

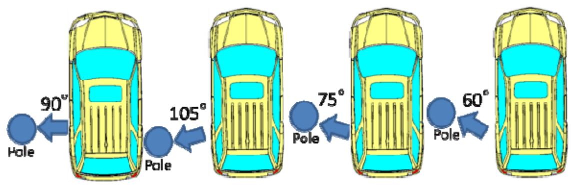

Figure 9. Image of side pole crash of angular difference.

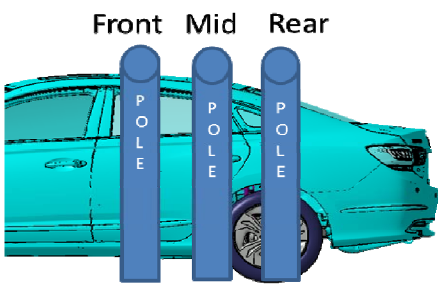

Figure 10. Image of side pole crash of position difference.

Table 1.
Conditions of simulation

Pole Diameter (inches)	Speed	Angle (deg)	Position	Total (modes)
10	Low Mid High	60 75 90 105	Front Mid Rear	36
5 15	Low Mid High	90	Front Mid Rear	24

The simulation data was acquired at the place shown in Figure 6.

Figure 11 and Figure 13 show all the simulation data of the low speed crash. Figure 11 uses SIS Gx and Gy, and Figure 13 uses yaw-rate and SIS Gy. A threshold value for deployment of airbag is set larger than the data of low speed crashes. Figure 12 and Figure 14 represent part of the simulation data. The high speed crashes was detected by SIS Gx and SIS Gy as shown in Figure 12. The middle speed crashes was detected by yaw-rate and SIS Gy as shown in Figure 14.The data in Figure 12 and Figure 14 were plotted up to the T-TTF and could be judged exceeding the threshold until the T-TTF. So it found that the required performance is satisfied.

Figure 12 and Figure 14 show the data of a part of the simulation, but we confirmed that the crash detection performance is satisfied in all data of the simulation which we conducted.

We found that the crash detection performance on the various side pole crashes was sufficiently satisfied even by the method of detecting vehicle behavior change.

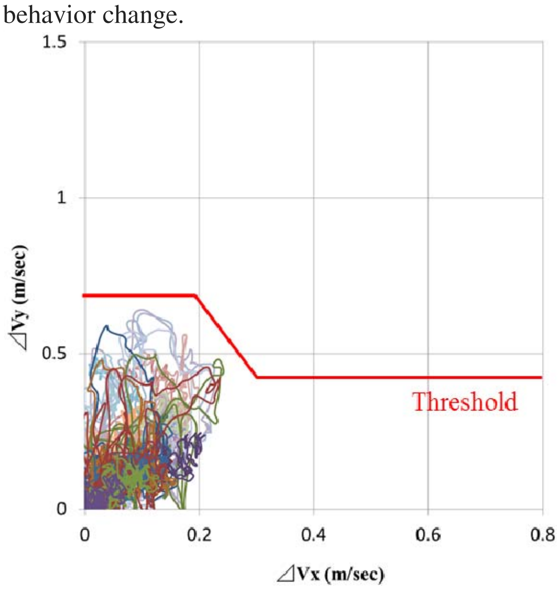

Figure 11. Simulation data of the low speed crash and this map is drawn by SIS Gx and SIS Gy.

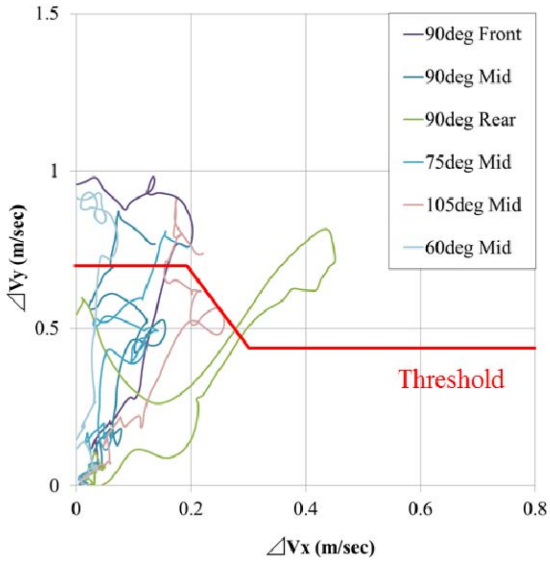

Figure 12. Simulation data of the high speed crash and this map is drawn by SIS Gx and SIS Gy.

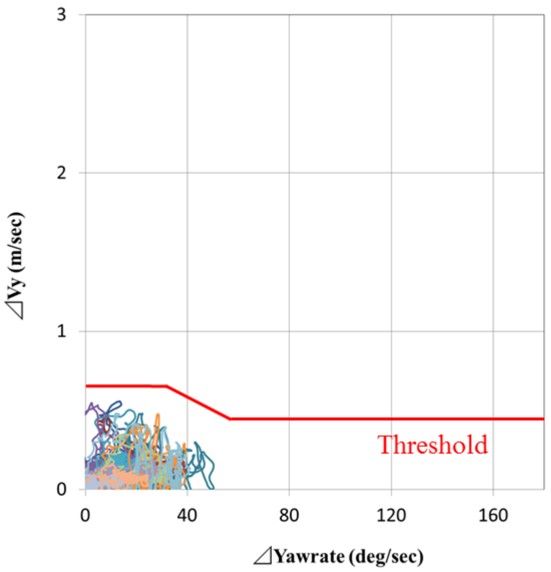

Figure 13. Simulation data of the low speed crash and this map is drawn by yaw-rate and SIS Gy.

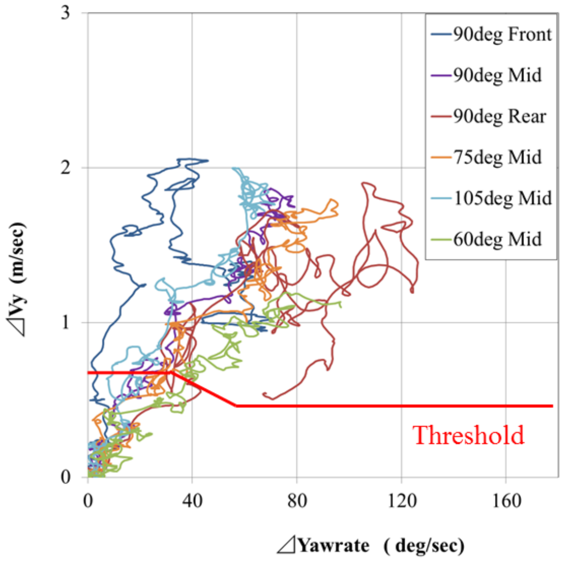

Figure 14. Simulation data of the middle speed crash and this map is drawn by yaw-rate and SIS Gy.

Verification in CBU test

We also carried out CBU tests which modes are shown as Table 2. Figure 15 and Figure 16 show the data of the CBU tests. Figure 15 uses SIS Gx and Gy, and Figure 16 uses yaw-rate and SIS Gy. A threshold value for deployment of airbag is set larger than the data of the low speed crashes. For middle speed and high speed crashes data, they were plotted up to the T-TTF. So the data could be judged exceeding the threshold until the T-TTF. So the required performance is satisfied.

Table 2.
CBU test Modes

Speed / Impact Position	Low	Middle	High
First seat side	Pole /MDB		
Second seat side	Pole	Pole	Pole

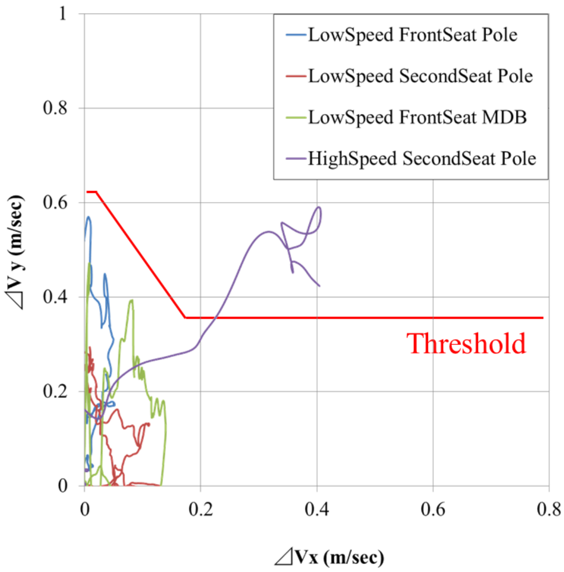

Figure 15. CBU data drawn by SIS Gx and SIS Gy.

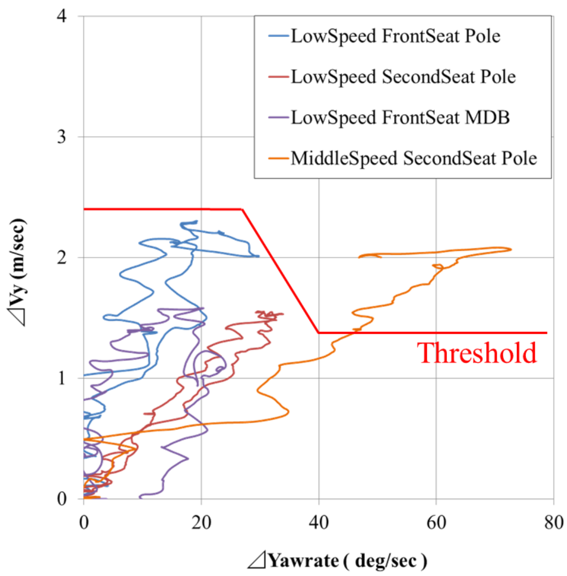

Figure 16. CBU data drawn by yaw-rate and SIS Gy.

DISCUSSION

Verification of misuse during normal driving

Vehicle behavior change also comes out during normal driving. So, we confirmed performance of the algorithm by CBU test.

We considered six modes. These test modes are driving circle, turn, lane change, spin on low µ road, riding on a curb of rear wheel and passing on split µ road.

In these modes, the yaw-rate comes out most as spin on low µ road. Therefore, the data of spin on low µ road is represented in Figure 16.

The duration of the data of the vehicle behavior change at the time of spinning is several seconds. However, the crash detection algorithm uses a difference value of several tens of msec. It can be seen that the time scale is completely different.

Therefore, as shown in Figure 17, the data stays close to the origin. So the misuse during normal driving is not a problem on the algorithm.

Moreover, the vertical axis of the algorithm is a physical quantity of intrusion. Since intrusion of body does not occur during normal driving, the data does not come out on the vertical axis. Therefore, it was found that the toughness is high for the misuse.

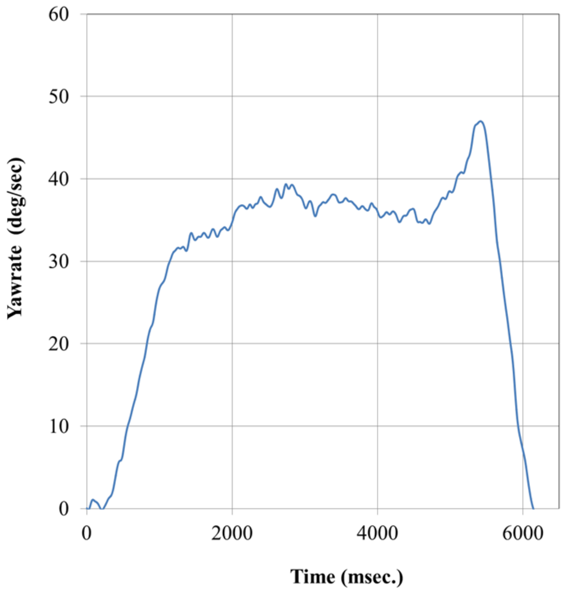

Figure 16. Yaw-rate data during spin on the low µ road.

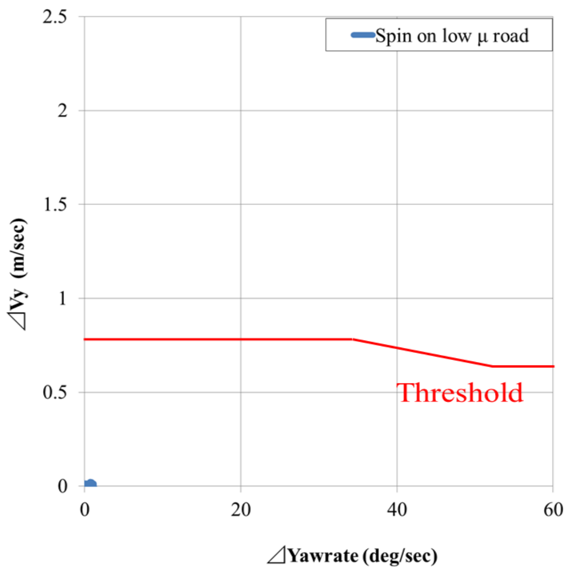

Figure 17. CBU data on the algorithm during spin on the low µ road.

Verification of influence on vehicle behavior change when center of gravity changes

Since vehicle behavior is used, we can consider that an influence will come out when center of gravity of vehicle changes. In vehicle with FF layout, as a case where position of center of gravity changes, it is conceivable that a heavy weight is fixed to the trunk room. We verified this condition using simulation.

The simulation was carried out in Accord based car with 300 kg weight fixed to trunk room. As the weight was fixed, the center of gravity of the vehicle moved about 300 mm rearward. The results of simulation show in Figure 19. As the center of gravity changed, the data changed slightly, but the crash detection performance was influenced little.

When the crash position changes to a position close to the center of gravity of the vehicle, in principle, intrusion becomes larger and vehicle behavior change becomes smaller, so it is expected that the path on the algorithm will change to upper left in the algorithm.

Although slight changes were observed according to this principle it was confirmed that the influence is quite small.

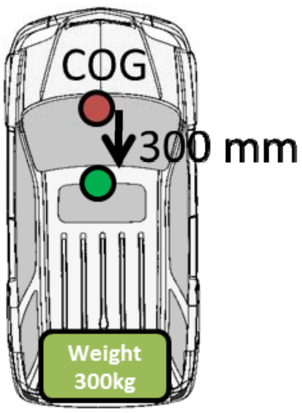

Figure 18. Image of the change of COG when heavy weight fixed to trunk room.

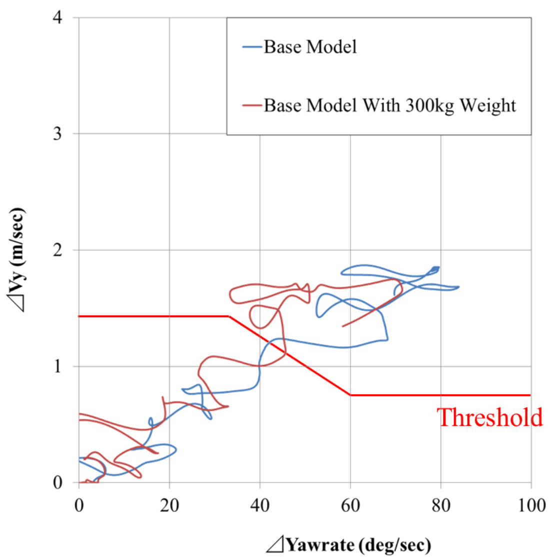

Figure 19. Data changed on algorithm when the vehicle center of gravity changed.

Detection performance of vehicles with third seat

Even in the case where the vehicle has a third seat, we also researched in the CBU test whether crash detection is possible with the sensor configuration shown in Figure 6.The CBU test was carried out using 1-box vehicle with a third seat. The CBU test modes are shown as Table 3. Figure 20 and Figure 21 show the data of the CBU test. The plot of the data was until T-TTF except the low speed crash data. In the crash of middle speed or more, the data exceeds the threshold. So, we confirmed the crash detection performance is satisfied.

As for the reason why the detection performance was satisfied with the side pole crashes of third seat side, when the crashes occurred farther from the center of gravity of the vehicle, the value of the vertical axis becomes smaller, but the value of the horizontal axis becomes larger. As a result, the data could be extended on the algorithm to a position far from the origin.

Although the data of SIS Gy is small, G sensor can detect. It can be considered that this is due to the fact that the member of body exists up to the third seat and the G data can be transmitted through this member.

If the body member does not exist up to the third seat, the data does not extend on the vertical axis of the algorithm. If the data only extend on the horizontal axis alone, it is difficult to judge the crash. This is because the vehicle structure is not compatible with the detection concept.

Table 3.
CBU test modes

Speed / Impact Position	Low	Middle	High
First seat side	Pole /MDB		
Second seat side	Pole	Pole	Pole
Third seat side	Pole	Pole	Pole

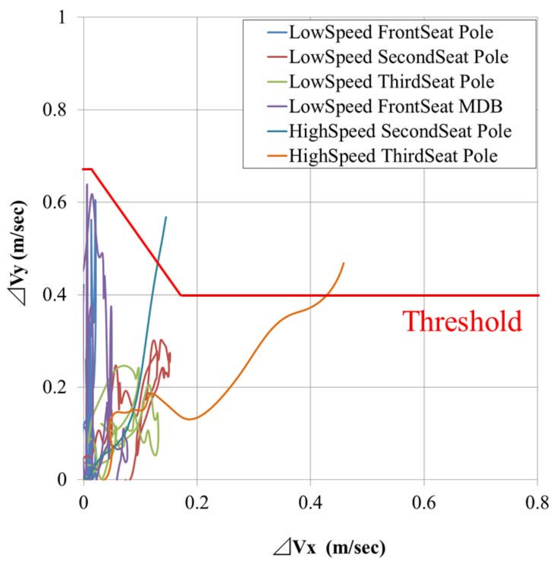

Figure 20. CBU data on the algorithm using SIS Gx and SIS Gy.

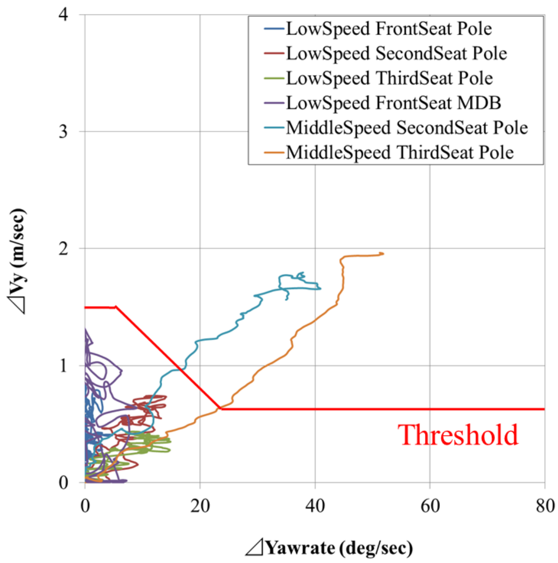

Figure 21. CBU data on the algorithm using yaw-rate and SIS Gy.

CONCLUSIONS

In this paper, we devised a crash detection algorithm using vehicle behavior change and intrusion of body from detection concept. We also researched its crash detection performance.

We confirmed that sufficient crash detection performance is obtained from the results of the simulation and the CBU tests.

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