

Identification of Object Impact Location and Bumper Stiffness Curve for Pedestrian Protection System

2011-01-0083

Published
04/12/2011

Seo-Wook Park and Robert Jones
Robert Bosch LLC

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doi:10.4271/2011-01-0083

ABSTRACT

A method for identification of object impact location and bumper stiffness curve is presented in this paper. The method calculates an offset distance of object impact based on intrusions obtained from three accelerometers mounted in the bumper fascia. The method also evaluates a center strength based on an absolute sum of acceleration. A characteristic line has been introduced in a two-dimensional domain consisting of intrusion-based offset and center strength. When test data are projected onto the characteristic line, an improved object impact location can be achieved. An intrusion curve over offset distance is obtained for impact tests striking at different locations with the same object and same speed. Then, a bumper stiffness curve can be identified by taking a reciprocal of the intrusion curve. This study shows a bumper stiffness curve can be used for an impact object classification for the pedestrian protection system.

INTRODUCTION

Safety regulations and consumer tests traditionally concerned about passenger safety in car crashes are now moving towards new rulemaking on pedestrian safety. In the majority of accidents involving pedestrians, the pedestrian collides with the vehicle bumper. Serious injuries can occur if the pedestrian's head strikes the engine hood [1]. As a result, both European regulation and Euro NCAP related to pedestrian protection require the reduction of the deceleration level during headform impact to fulfill the head protection criteria (HPC) at the front hood of the vehicle [2,3]. To comply with tougher criteria, a vehicle needs a free deformation space below the engine hood. However, due to the design restrictions and engine components under the hood, it would be preferable for car makers to adopt an active pedestrian

protection system to lift up hoods when pedestrian impact is detected [4,5].

An active pedestrian protection system consists of an electronic control unit, sensors and reversible/irreversible actuator. A variety of sensor technologies are being used for pedestrian impact sensing such as accelerometers, optical pressure sensors or force sensitive resistors [6, 7, 8, 9, 10]. Generally, they can be divided into two groups: remote sensors like video cameras or ultrasound that sense the pedestrian before the crash, and contact sensors that sensor the pedestrian after the first impact. The second group sensors have much less time for the detection and firing of an actuator system in compare with remote sensors [5]. Gwennael Gate et al. used a laser scanner to detect a pedestrian. This kind of sensors requires a sophisticated algorithm and a complicated electronics [6]. Werner Bieck et al. utilized a foil-type switching element to detect an impact object. The system complexity and cost seems to be relatively high [7]. Bernhard Mattes et al. suggested using a multiple sensors such as pressure sensor, deformation sensor and acceleration sensor. However, it seems to be practically hard to use many different types of sensors due to system cost and complexity [8]. Tetsuya et al. adopted a force sensitive resistor (FSR) sensor to detect a collision width. The FSR sensor requires a complicated electronics for the signal processing [9]. Shinichi et al. used multiple acceleration sensors and calculates a deformation rate to discriminate a pedestrian from non-pedestrian. However, they didn't take the non-uniform bumper stiffness into consideration [10].

In this study, accelerometer technology has been selected by considering sensor cost, system complexity and system performance. Sensing technology using accelerometers has been already developed and proven for many years in the



Figure 1. An electronic pedestrian protection system using three accelerometers mounted in the bumper fascia

field of vehicle crash detection. Furthermore, the accelerometer cost is relatively reasonable compared to other sensors such as fiber optic cable.

One of the challenging tasks for pedestrian impact sensing is how to identify an object impact location on the bumper [10]. The difficulty of identifying object impact location is due to the fact that bumper stiffness is not homogenous and sensing area of the bumper is relatively wide. Therefore, it requires a sophisticated algorithm to overcome these challenges.

This paper adopts an electronic pedestrian protection system using three accelerometers mounted in the bumper fascia. The object impact location from the bumper center is calculated by the difference of intrusions detected at the left and right sensors. However, it is hard to achieve a clear recognition of impact location with only intrusion-based offset value due to its simplicity of calculation. In order to overcome the drawback, this paper introduces another measure called center strength, which represents impact strength at the bumper's center location. The proposed method defines a characteristic line having a -45° slope in the two-dimensional domain consisting of the intrusion-based offset and center strength. The analysis data points for different impact tests are projected onto the characteristic line. The projected offset value shows a clear separation for different impact locations. The projected offset value can be used for an identification of a bumper stiffness curve.

When an object strikes the vehicle bumper, the bumper deforms differently depending on an object's mass, impact speed and the bumper stiffness. As for object impacts having the same mass and speed, the bumper intrusion is inversely proportional to the bumper stiffness based on a simple spring-mass model. A bumper intrusion curve over the bumper

width is calculated using impact test data with the same object mass and speed at different impact locations. A bumper stiffness curve can be identified by taking a reciprocal of the intrusion curve. It is important to note that an accurate estimation of impact location is crucial to identify the bumper stiffness curve. The bumper stiffness curve can be used for an impact object classification, which is the most important task for pedestrian protection system.

OBJECT IMPACT LOCATION

Figure 1 shows a schematic diagram of an electronic pedestrian protection system using three accelerometers mounted in the bumper fascia. This figure shows an example of active popup hood system. Figure 2 illustrates an overall structure of the proposed pedestrian detection algorithm.

The acceleration signals are integrated to obtain delta velocities, Dv , and double integrated to calculate intrusions, Ds , at the location of each sensor. A dominant impact sensor is identified by comparing the intrusion for each sensor. The dominant impact sensor is the one closest to the impact location. The delta velocity of the dominant impact sensor is used to determine a "freeze time". Recognition of impact location is very uncertain in the beginning of an impact. Once the impact location is identified, it should be frozen before the object starts rebounding. Figure 3 shows how to define the freeze time based on the delta velocity of the dominant impact sensor. This delta velocity plot shows a typical pattern of impact object behavior while an impact progresses. When the delta velocity of the dominant impact sensor, $Dv_{dominant}$, exceeds a predefined up-threshold ($DvThdUp$), the decision of the dominant impact sensor is locked. The freeze time is determined when $Dv_{dominant}$ drops below down-threshold, $DvThdDn$. Because the data received from the sensors while

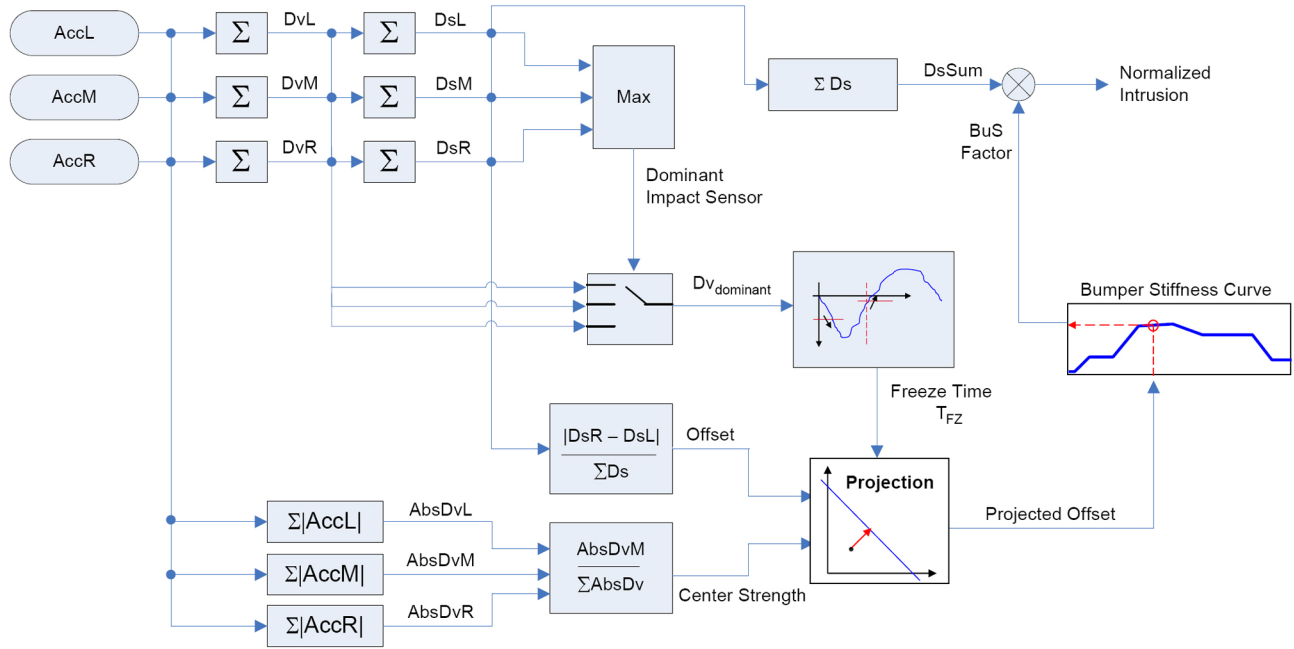


Figure 2. Overall structure of proposed pedestrian detection algorithm

the bumper fascia is rebounding is not indicative of the intrusion caused by the object, any data received after the freeze time will not be used to determine the impact location (or offset from bumper center). The threshold values include a hysteresis to avoid unwanted result due to noise.

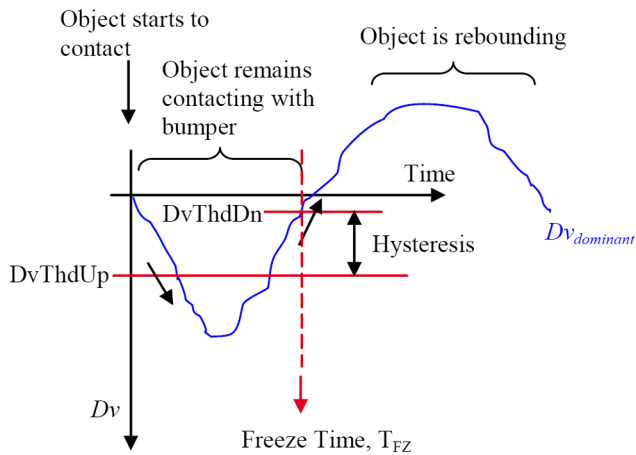


Figure 3. Definition of freeze time

After the dominant sensor is identified and the freeze time has been determined, the system proceeds to determine the impact location or the distance of the impact from the center of the bumper. The offset calculation is based on an intrusion value from each sensor at the freeze time. As described above, the intrusion value is obtained by determining the double integral of the acceleration signal from each of the three sensors. Figure 4 illustrates an example of how the intrusion on the bumper fascia is detected at the location of

each sensor. The impact occurs at a distance c from the center of the bumper. The maximum intrusion should occur at the impact location. We can notice that sign of delta velocity changes (deceleration to acceleration) in the vicinity of the “freeze time”. Assuming an instantaneous equilibrium state at the freeze time, we can apply a rotational equilibrium equation stating that the sum of rotational forces, or torques, with respect to bumper center position should be zero.

$$\sum M_{\text{center}} = 0 \quad (1)$$

An object impact force can be roughly estimated by multiplying an intrusion by bumper stiffness. The torque at each sensor with respect to bumper center position can be expressed by

$$M_{\text{center}} = \text{Stiffness} \times \text{Intrusion} \times \text{Offset Distance from Center} \quad (2)$$

For simplicity, assuming the bumper stiffness is uniform at each location across the bumper fascia, the rotational equilibrium can lead to the following equation.

$$DsL \times (d - c) = DsM \times c + DsR \times (d + c) \quad (3)$$

Where DsL , DsM , DsR are intrusions at the left, center, and right sensor respectively. d represents the distance between center and left/right sensors. c denotes offset distance of the impact location from the bumper's center.

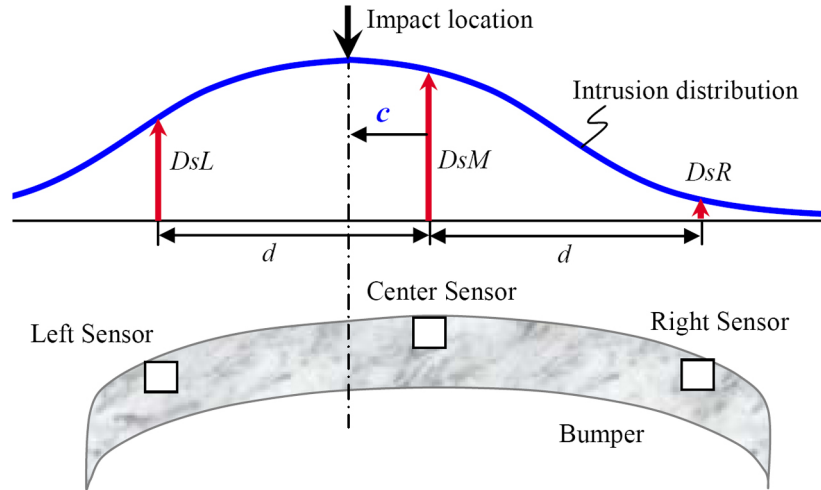


Figure 4. An example of impact at offset distance, c

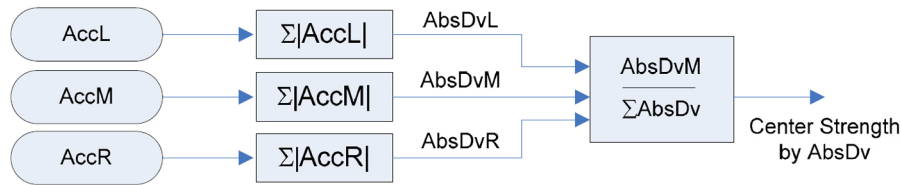


Figure 5. Calculation of center strength

Therefore, the normalized offset value of the impact from the center of the bumper can be obtained by the following equation.

$$\frac{c}{d} = \frac{DsL - DsR}{DsL + DsM + DsR} = \frac{DsL - DsR}{\sum Ds} \quad (4)$$

However, the assumption that the stiffness of the bumper is uniform is not accurate. This assumption may be valid only if the bumper exhibits an elastic deformation range. As such, the method illustrated in Figure 2 evaluates other aspects to determine a more accurate projected offset value. One other aspect that is evaluated by the system is the proportion of the impact strength exerted on the center of the bumper fascia (hereinafter, the “center strength”). An absolute sum of acceleration is calculated for each sensor as shown in Figure 5. The absolute sum of acceleration represents impact strength.

$$AbsDv = \sum |a| \quad (5)$$

The center strength is calculated according to the following equation.

$$S_{CTR} = \frac{AbsDvM}{AbsDvL + AbsDvM + AbsDvR} = \frac{AbsDvM}{\sum AbsDv} \quad (6)$$

The center strength value is indicative of the amount of impact strength detected at the center location of the vehicle bumper.

The initial offset value and the center strength value are then subjected to a two-dimensional domain analysis in which each combination of center strength and initial offset value are projected onto a characteristics line having a -45° slope. Projecting the values onto such a characteristics line is appropriate because an impact with a small offset from center will have a high center strength value and an impact with a large offset from center will have a low center strength value. Figure 6 illustrates how the data points are projected onto the characteristics line. The projected point on the characteristics line is defined as the point at which a line extending from the actual data point (center strength, offset) intersects perpendicularly with the characteristics line, which can be calculated using the equations illustrated in Figure 6.

Figure 7 shows experimental data points for child legform impact with 20km/h relative to the characteristics line. The child legform weighs 9.5kg provided by an OEM.