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VEHICLE CRASH ANALYSIS FOR AIRBAG DEPLOYMENT DECISION

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ABSTRACT−Airbag deployment has been responsible for huge death, incidental injuries and broken bones due to low crash severity and wrong deployment decision. This misfortune has led the authorities and the industries to pursue uniquely designed airbags incorporating crash-sensing technologies. This paper provides a thorough discussion underlying crash sensing algorithm approaches for the subject matter. Unfortunately, most algorithms used for crash sensing still have some problems. They either deploy at low severity or fail to trigger the airbag on time. In this work, the crash-sensing algorithm is studied by analyzing the data obtained from the variables such as (i) change of velocity, (ii) speed of the vehicle and (iii) acceleration. The change of velocity is used to detect crash while speed of the vehicle provides relevant information for deployment decision. This paper also demonstrates crash severity with respect to the changing speed of the vehicle. Crash sensing simulations were carried out using Simulink, Stateflow, SimMechanics and Virtual Reality toolboxes. These toolboxes are also used to validate the results obtained from the simulated experiments of crash sensing, airbag deployment decision and its crash severity detection of the proposed system.

KEY WORDS : Crash sense, Severity, Deployment decision

1. INTRODUCTION

Nowadays most of the automotive manufacturers are equipped with standard airbag system in their vehicle to reduce fatalities and mitigating injuries significantly. With the increasing number of incidents, despite the effectiveness of airbags evidenced by statistics, a number of inadvertent fatalities and injuries have been caused by airbag deployment. This is due to close proximity between the occupant and the airbag module during deployment. Therefore, the airbag system needs to consider airbag deployment based on the size and position of the detected occupant prior to deployment. Additionally factors, which influence airbag deployment such as crash severity, vehicle velocity, acceleration (Dorel and Wang, 2003) and other relevant information can be used to create a smart airbag system.

Under normal circumstances, the airbag deploys itself if the collision force is equivalent to a frontal collision with a stationary barrier at a speed of 14 mi/hr i.e. 22.54 km/hr or higher. Upon getting the triggering signal from the various sensors like the airbag occupant sensor, safe distance decision sensor and crash sensors, it will take 30 ms to deploy (Chaikin, 1991). Sensors are the brain and nerves of the airbag system. Their responsibility is to detect the occurrence and to judge the severity of an impact. Since the emphasis of this paper is on crash sensing, discussion here are mostly limited to crash related facts. The crash sensor does not only determine the airbag deployment, but also predicts crash severity and its type. It even monitors whether the deployment decision is correct or not (David *et al.*, 2001). Crash types and its sensor are widely investigated in the literature (Chan, 2002a). The former include barrier crash, pole crash and the latter involves mechanical and an electronic sensor. In 1980s to 1990s, most crash sensors used were mechanical, electromechanical and magnetomechanical as explained in Shinto *et al.* (1991). Sensor calibration and damping effect are the drawback of the above sensors (Shinto *et al.*, 1991).

An electronic sensor is more effective as its signal can be easily digitized and analyzed in order to study the characteristics of different crash types. On the contrary, the design of an effective crash sensing system is technically challenging. Many electronic sensing methods have been designed for the airbag systems that include the detection of speed change (Chan, 2000), acceleration based signal processing using accelerometer sensor such as piezoelectric or micromachined approaches and for side impact pressure or acceleration sensing scheme

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(Mazur,1996). However, size, cost, sensitivity, offset, output noise and EMI effects still need to be considered when choosing the electronic sensor. A mechanical arming sensor based on logic level electronic is often incorporated with electronic crash sensor to reduce the potential for inadvertent deployment in presence of certain faulty conditions or EMI effects (Smith and Kincaid, 1998).

The core element of electronic sensor is the sensing algorithm, which made the decision for airbag deployment. A number of algorithms have explained various approaches for implementing the sensing scheme. For instance, using predictions of occupant displacement to establish an optimal triggering, in which Kalman filtering of crash data and calculation of jerk, acceleration, velocity and displacement are considered (Chan, 2002a). However, the review on the crash algorithm in (Chan, 2002b) does not address a complete set of airbag deployment schemes. It has a number of problems such as the untimely and unnecessarily deployment of airbags (i.e. either the airbags are not deployed on time or they trigger even at low speed crashes). Additionally, airbag deployment performance, robustness, calibration, flexibility and complexity of the sensing algorithms in (Mclyer, 1996) are also not well proven.

This paper deals with the performance of a simulated crash model and its algorithm to sense crash, its severity factor and the airbag deployment decision. Out of many possible parameters, the proposed algorithm in this work uses the displacement, vehicle speed and acceleration parameters. The crash sensing function of the state flow controller senses a crash based on the change of vehicle velocity that provides deployment decision along with crash speed condition. The detection of severity depends on the vehicle speed at time of crash. In sensing crash, a threshold of change velocity is considered, in which it compares with the change of velocity to detect crash sensing ability. The threshold is based on acceleration, velocity and displacement of the vehicle. For deployment decision, vehicle speed at the time of crash is considered as a condition for deployment and its crash severity is determined. The ultimate goal of this paper is to sense crash, determines its severity and timely deploys airbag to increase the effectiveness and safety of the occupant restraints system.

2. CRASH SENSING ALGORITHM AND MODELING APPROACH

In this section, the modeling and crash sensing algorithm design approach is discussed by analyzing the crash data in terms of performance, robustness, flexibility and complexity of the airbag deployment as shown in Figure 1. This adopted approach is highly recommended in estimating and detecting crash to provide a probable deployment or non-deployment decision.

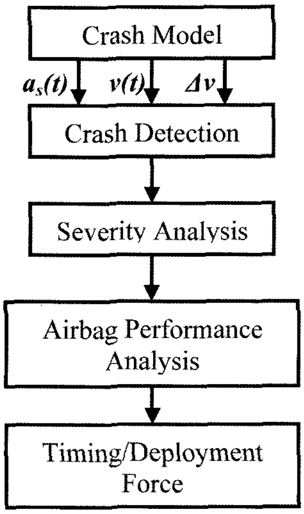

Figure 1. Flow chart of crash modeling approach.

Basing on Figure 2, which depicts typical crash detection operating characteristics, we develop an accurate crash detection algorithm and sensor system design.

The subsequent example intends to demonstrate the various crash detection algorithm operating characteristics and their system performances in which our proposed algorithm or sensor system has been designed to timely and correctly deploy the airbag upon detecting high severity crashes. On the other hand, the system will not deploy the airbag for low severity crashes, rough road events etc.

In Figure 2, the vertical axis represents the probability of timely airbag deployment whilst the horizontal axis represents probability of unwarranted airbag deployment. Respectively, the coordinates (0,1) and (1,0) mark the most optimal and worst operating characteristics for the crash detection algorithm. The better the algorithm the closer it will be to the optimal point of (0,1).

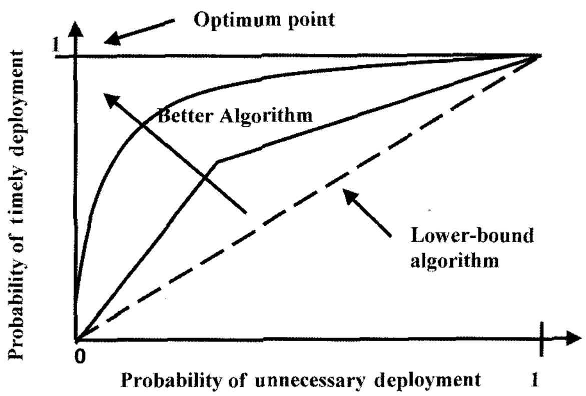

Figure 2. Crash detection operating characteristics.

A good design of crash sensing algorithm must have the following characteristics: a) predictive and judgmental ability about crash severity, b) discriminative decision of deployment or non-deployment and d) real time application. As such, many parameters can be used to perform the sensing of crash like the change of velocity, change of energy, acceleration and jerk (derivative of acceleration). However, change of energy is not suitable in a real time implementation since the severity of consecutive crashes remain the same. In order to develop the algorithm, we first investigate a number of basic parameters to determine the crash severity and airbag control. These basic parameters are accelerometer signal, $a_s(t)$, change in vehicle velocity, $\Delta v = \int a_s(t)dt$, and vehicle speed, $v(t) = \int a_s(t)\, dt + v_0$, where v_0 is the initial velocity of the vehicle. These parameters are described briefly as follows.

2.1. Change in Vehicle Speed

Change in vehicle speed is one of the most important parameter for crash detection and its modeling development. Table 1 shows relationships of various speeds condition with respect to safety and control action when designing a crash model.

The NHTSA (National Highway Traffic Safety Administration) standard airbag system requires that the airbag must be deployed if the collision force is equivalent to a frontal collision with a stationary barrier at a speed of 22.54 km/h or higher. On the other hand, if the collision force is equivalent to a barrier-crash at a speed of 12.88 km/h or less, the airbag should not deploy. If the collision force is neither (i.e. 12.88 km/h < $v(t)$ < 22.54 km/h), then we can safely assume that the crash has occurred in the neutral zone. If a crash were to occur in this zone, then there is no requirement as far as the triggering of the airbag is concerned, which implies that a deployment or a non-deployment of the airbag is equally acceptable if a crash occurs in the said zone.

2.2. Change in Vehicle Velocity (Δv)

The change in velocity, Δv is obtained by computing the integration of the acceleration signal. This variable is an essential parameter in crash detection and presents in almost all algorithms. If the change in vehicle velocity, Δv is selected as a parameter for triggering the airbag, then we must determine a threshold value of Δv which can be used to make a decision whether or not the crash occurred in the deployment zone. Such a threshold value can easily be determined for barrier crashes only. As an example, referring to Figure 3, one can easily select an appropriate threshold value, v_{th}, to trigger the airbag for a 14 m/h (or 22.54 km/h) crash, which is the lowest speed of crash that requires an airbag deployment. If $\Delta v \geq v_{th}$, then it is certain that the crash has occurred in the danger zone which requires a 'must deploy' decision and therefore, the airbag must be triggered, regardless of the type of crash. The dotted box of Figure 3 represents the SIMULINK block diagram of the crash decision for the whole system.

Table 1. Speed for crash algorithm and model development.

Speed	Zone	Desicion
Below 8 m/h (12.88 km/h)	Safe	No deployment
Within 8–14 m/h (12.88-22.54 km/h)	Neutral	Optional deployment
Above 14 m/h (22.54 km/h)	Danger	Must deploy

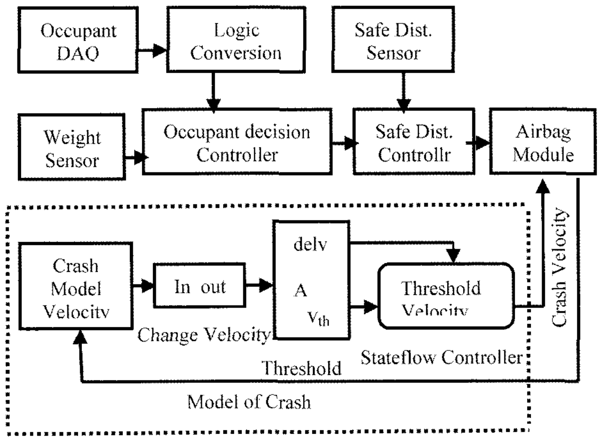

Figure 3. SIMULINK model for crash decision.

2.3. Vehicle Acceleration

There is no doubt that during a crash the accelerometer signal, $a_s(t)$ contains vital information about the crash. It can be assumed that the signal $a_s(t)$ contains two components: the vehicle acceleration component and the noise component. Thus, we can write,

$$a_s(t) = a(t) + n(t) \tag{1}$$

where $a(t)$ is the vehicle acceleration component and $n(t)$ is the noise component. During a crash, the vehicle acceleration component, $a(t)$ is a negative number (i.e. deceleration). The component $a(t)$ also contains important information about the crash. The noise component depends on several factors, such as the location of the accelerometer, vibration and deformation of the vehicle during a crash. For example, if the accelerometer is placed at the front compartment of the vehicle, then the noise component is higher than if it is placed in the passenger compartment. Normally the accelerometer

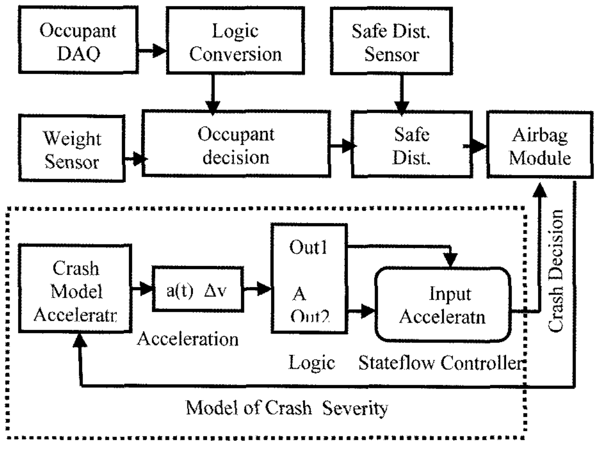

Figure 4. SIMULINK model for crash severity.

signal produces too much noise if it is located at a soft part of the vehicle, or in that part of the vehicle, which is vulnerable to a crash. In order to design a good electronic crash sensor it is desirable to place the accelerometer at the least noisy location in the vehicle, so that the vehicle acceleration component, $a(t)$, can easily be separated from the accelerometer signal, $a_s(t)$. The dotted box of Figure 4 represents the crash severity decision of the SIMULINK block-diagram model of the whole system.

3. ALGORITHM AND DEPLOYMENT DECISION

In order to detect crash, its severity and airbag deployment decision the following algorithm is developed. The basic structure of the algorithm consists of three states: NORMAL, STANDBY or FIRE, which are described in terms of their object, input, output and the approach used as shown in Figure 5. It is implemented by a sequential state flow. Initially, it determines the change of velocity, Δv and checks the following conditions: $\Delta v \geq v_{th}$ or $\Delta v < v_{th}$, where v_{th} is the threshold value of Δv.

i) If $\Delta v \geq v_{th}$, while output ='2'; DECISION: Crash is detected and shifts to standby state.

ii) If $\Delta v < v_{th}$, while output ='1'; DECISION: Crash is not detected and back to normal state.

The speed-based algorithm is responsible in making the decision whether or not the airbag is deployed. As such, the algorithm needs to determine the vehicle speed and compares it to the threshold speed of 22.54 km/h, i.e. vehicle speed, $v(t)$ 22.54 km/h or $v(t) < 22.54$ km/h. The decision-making algorithm steps are as follows:

i) Once the crash detection algorithm gives its decision, the speed based algorithm decision mode is activated.

ii) If crash is detected and the speed, $v(t) \geq 22.54$ km/h, the output is set to '1' and the airbag is set to 'FIRE' state.

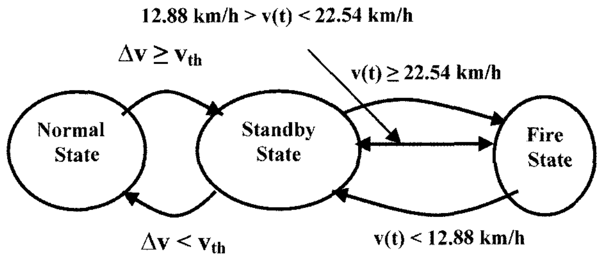

Figure 5. State diagram of decision making circuit.

iii) However, if the speed of the vehicle, $v(t)$ is between 12.88 and 22.54 km/h, then the crash is said to have occurred in the gray/neutral zone.

iv) Finally, if crash is detected but the speed, $v(t) < 12.88$ *km/h*, then the output is set to '0' which means the decision return to 'STANDBY' state.

An increase in vehicle speed during crash increases the crash severity factor. The change of velocity, Δv, over a period of time, T, at the firing state can be computed by integrating either $a_s(t)$ or simply a(t) signal since the integral over the noise component is approximately zero. Mathematically, this implies that

$$\Delta v = \int_0^T a_s(t)\, dt$$
$$= \int_0^T a(t)\, dt + \int_0^T n(t)\, dt = \int_0^T a(t)\, dt \qquad (2)$$

The circuit for computing Δv can be designed using systolic architecture to achieve the real-time speed. The outputs during the firing state are fed into a state flow circuit that will then make the airbag deployment decision. As such, the decision making circuit can be implemented as a synchronous sequential machine with only three states: NORMAL, STANDBY and FIRE. The state diagram of this sequential machine is shown in Figure 5.

4. RESULTS AND DISCUSSION

The crash detection model for an airbag deployment system has been simulated using Simulink, Stateflow, Sim-Mechanics and Virtual Reality of Matlab tools. The developed model was used to analyze the vehicle crash performance in terms of the crash severity factor and deployment decisions. In this section, simulation results are presented and discussed. To illustrate the performance of our approach, some exemplary results obtained from the developed system are demonstrated in order to explain the accuracy of the airbag deployment decision and crash severity.

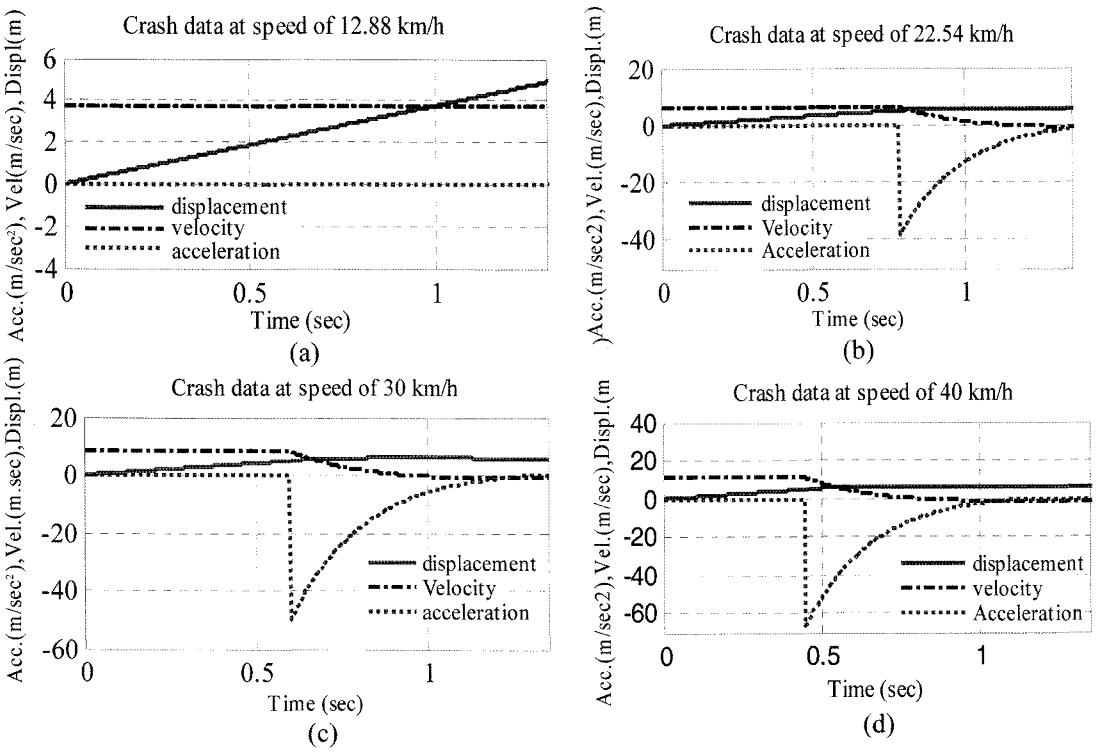

Figure 6. Crash data results at various speeds.

Shown in Figure 6 are the simulated results obtained in terms of acceleration, velocity and displacement. Figure 6(a), 6(b), 6(c) and 6(d) represent vehicle crash data at various speeds of 12.88 km/h, 22.54 km/h, 30 km/h and 40 km/h, respectively. It was mentioned earlier that the airbag must not deploy if the speed is less than 12.88 Km/h (or 8 m/h). However, it must deploy if the speed is 22.54 km/h (or 14 m/h) or higher. As shown in Figure 6(a), when the speed is 12.88 km/h, the airbag is not deployed since the velocity is constant, displacement is proportional with respect to time while acceleration is zero (null condition). However, in Figure 6(b), (c) and (d), the airbag is deployed since the speed are all greater or equal 22.54 km/h. In Figure 6(b), the airbag is deployed at time equals 0.78 sec in which the vehicle velocity starts to drop to zero, displacement becomes static and deceleration at time of crash is 39 m/sec^2. Similarly, the airbag is deployed at 0.60 sec and 0.45 sec for the other 2 cases of vehicle speed at 30 km/h and 40 km/h, respectively. The results also proved that the higher the vehicle speed, the greater the deceleration factor would be which in turn causes a greater crash impact and resulting with faster airbag deployment time. Figure 6(b), 6(c) and 6(d); represent the crash data results at the speed of 22.54 km/h, 30 km/h & 40 km/h, respectively.

As such, we conclude that deceleration is a good

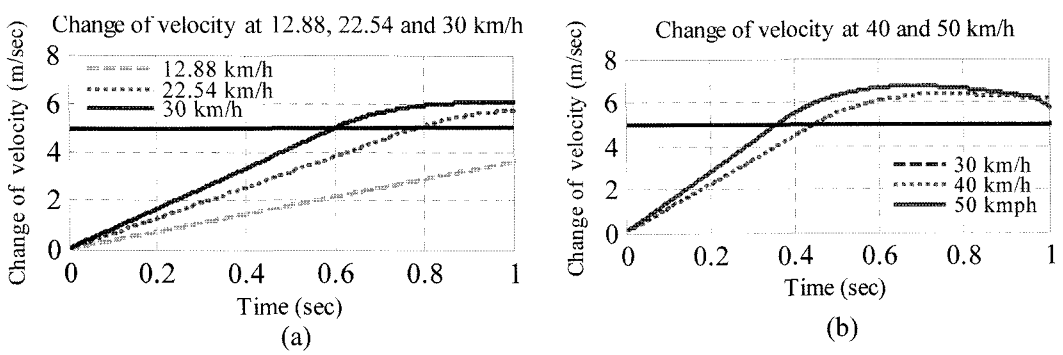

Figure 7. Crash detection with changing velocity of the vehicle during crash.

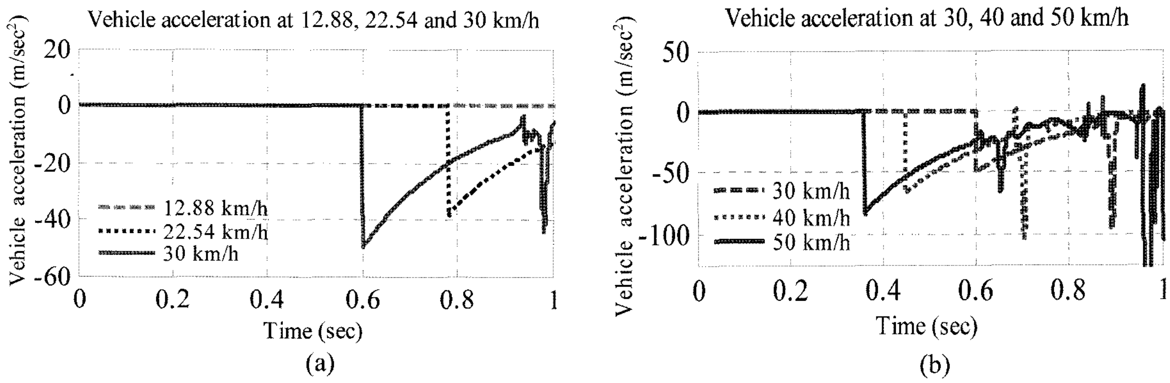

Figure 8. Crash data of vehicle acceleration at various speeds.

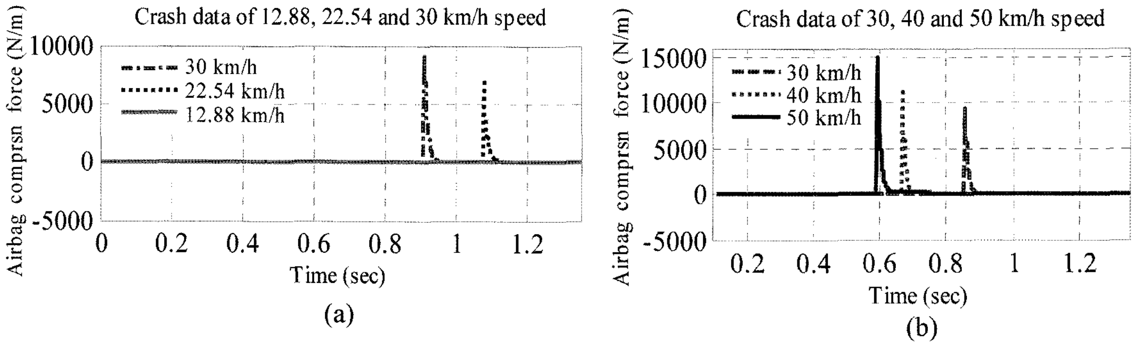

Figure 9. Airbag compression force during various crashes.

parameter to determine crash severity and thus provide a good decision for airbag deployment/non deployment action at time of crash. Figure 7(a) and 7(b) show the curves of change in vehicle velocity for five different simulated crashes. The change in vehicle velocity, Δv is considered as a parameter for triggering the airbag. Therefore, we select a constant, v_{th}, value of 5 m/sec as a threshold. At this threshold value, simulation results shows that the airbag was not deployed at a 12.88 km/h crash, since its change in velocity does not exceed the threshold value for airbag deployment. As when Δv exceeds v_{th} (i.e. $\Delta v \geq v_{th}$) during a crash, the airbag was deployed. Figure 7 shows the various crashes were detected at 0.78 sec, 0.60 sec, 0.45 sec and 0.35 sec at the velocity of 22.54 km/h, 30 km/h, 40 km/h and 50 km/h, respectively. Thus, the greater the collision impact i.e. speeds, the earlier the airbag is deployed.

The acceleration signal also contains vital information about the crash. Figure 8 shows the acceleration signals during various crashes. From the simulation results, we found that the vehicle acceleration component *a(t)* is a negative number during crash. This indicates that deceleration is occurring. It can be seen that the deceleration are 38 m/sec^2, 50 m/sec^2, 62 m/sec^2, and 80 m/sec^2 at the various speed of 22.54 km/h, 30 km/h, 40 km/h and 50 km/h, respectively as shown in Figure 8(a) and 8(b). Thus, the higher the vehicle speed is, the greater the deceleration will be. Higher deceleration factor results in higher compression force, which in terms makes the crash more severe. It is also noted that the noise component increases in the same way, which may be related directly to the increase of crash severity.

The output of the simulink model of the airbag compression force is measured for various crashes. The results are shown in Figure 9(a) and (b). It can be seen that the compression force varies at different crashes during airbag deployment. The compression force output depends on the crash severity of the system. Previously, it was stated that as velocity increases the severity factor also increases, which in turn increases the compression force. This is a situation that put the occupant at a higher risk. During the various simulated crashes, the detection system gained a huge force of ~4000 N/m to ~15000 N/m and these forces are released when the airbag is being deployed as shown in Figure 9(a) and 9(b).

5. CONCLUSION

This paper describes a simple but functional algorithm that has been used to develop a crash detection model for airbag deployment system. The model is simulated to determine the crash severity impact and airbag deployment decision. The algorithm is based upon three main parameters of displacement, speed and acceleration. Displacement is used to detect a crash, speed is used to determine airbag deployment decision and acceleration determined the severity of the crash. We have tested our algorithm by applying a number of crash data to evaluate the performance of the system model. The simulation results obtained prove that the proposed system can effectively detect crash, make timely and correct airbag deployment decision and provide information about the severity of the crash. In conclusion, this study has proven that at high speed, the vehicle will suffer greater severity due to sudden and forceful deceleration. As a result, the time taken for the airbag to deploy will be shorter and amount of force release will be higher.

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