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Decision Algorithm for Smart Airbag Deployment Safety Issues

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***Abstract*—** Airbag deployment has been known to be responsible for huge death, incidental injuries and broken bones due to low crash severity and wrong deployment decisions. Therefore, the authorities and industries have been looking for more innovative and intelligent products to be realized for future enhancements in the vehicle safety systems (VSSs). Although the VSSs technologies have advanced considerably, they still face challenges such as how to avoid unnecessary and untimely airbag deployments that can be hazardous and fatal. Currently, most of the existing airbag systems deploy without regard to occupant size and position. As such, this paper will focus on the occupant and crash sensing performances due to frontal collisions for the new breed of so called smart airbag systems. It intends to provide a thorough discussion relating to the occupancy detection, occupant size classification, occupant off-position detection to determine safe distance zone for airbag deployment, crash-severity analysis and airbag decision algorithms via a computer modeling. The proposed system model consists of three main modules namely, occupant sensing, crash severity analysis and decision fusion. The occupant sensing system module utilizes the weight sensor to determine occupancy, classify the occupant size, and determine occupant off-position condition to compute safe distance for airbag deployment. The crash severity analysis module is used to generate relevant information pertinent to airbag deployment decision. Outputs from these two modules are fused to the decision module for correct and efficient airbag deployment action. Computer modeling work is carried out using Simulink, Stateflow, SimMechanics and Virtual Reality toolboxes.

***Keywords*—**Crash severity analysis, occupant size classification, smart airbag, vehicle safety system**.**

I. INTRODUCTION

IN recent years, research on enhancement of the safety of vehicle occupant receives great attention and has became an important research area in automobile engineering. Related safety issues being studied among others include occupant classification and detection, and crash severity analysis. Nowadays, most of the manufactured automobiles are equipped with standard airbag systems to improve the safety of the occupant [1, 2]. Despite the effectiveness of airbags evidenced by statistics, a number of inadvertent fatalities and severe injuries caused by airbags have been reported. Majority of these reported incidents involve children [3]. Imagine the airbag being deployed at a speed up to 200 mph to a child or small adult occupant. During a crash, if the child or small adult is in close proximity to the airbag module, the airbag deployment can be very harmful instead. Hence, an airbag system that employs and adapts the most appropriate technology is critically needed in the market.

In [4, 5], several sensing methods that address the aforesaid problems have been presented, patented and released. Various algorithms or threshold constants are applied depending on the automobile type. However, the development of a straightforward airbag deployment algorithm is difficult to cater for various types of automobiles [6]. Despite tremendous research efforts done recently in detection, classification of occupant and severity of the vehicle crash under various approaches and algorithmic conditions, the real time issues and robustness of algorithms are still a major concern for safe airbag applications [3, 7 & 8].

In the airbag system, sensors act as the brain and nerves [9]. Under normal circumstances, upon getting the triggering signal from the various sensors like the occupant sensor, safe distance decision sensor and vehicle crash analysis sensors (e.g. accelerometers), its sensing algorithm must determine the occupant position, perform classification and evaluate severity of the crash prior to making deployment decision. Usually, an 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 [10]. A number of algorithms involving various implementation approaches of the sensing schemes have been presented. For instance, [11] considers filtering of crash data and vehicle parameters using Kalman to predict occupant displacement to establish an optimal triggering condition. However, thus far the studies on crash sensing systems are neither complete nor well proven. Normally it does not address a complete set of airbag deployment schemes and it also does not deal with problems of untimely and unnecessary deployment of airbags (i.e. either the airbags are not deployed on time or they trigger even at low speed crashes) [12]. Additionally, issues such as airbag deployment performance, robustness, calibration, flexibility

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and complexity of the sensing algorithms are also not well proven [13].

To overcome the lack of detail and proven explanation in the aforesaid crash sensing algorithms, this paper presents a comprehensive discussion on the performance of the crash sensing system model and its related algorithms. In this work, we will focus on the impact of frontal collisions and propose a crash sensing system model that also satisfies the ‘5-10-20’ NHTSA standard rule [14] for safe distance airbag deployment. The proposed crash algorithm uses vehicle speed change, velocity and acceleration to provide vehicle crash severity data for correct and timely airbag deployment decision. In short, the ultimate goal of this work is to develop a crash sensing algorithm that detects front seat occupancy, performs occupant size classification, safe distance computation and crash severity analysis in order to regulate the airbag deployment so as to increase the overall effectiveness and safety of the occupant restraint systems.

II. PRINCIPLE OPERATION AND MODELING APPROACH

In this section, the principle operation and modeling of the overall occupant detection and crash sensing system is discussed with respect to its performance, robustness, flexibility and complexity of airbag deployment. The subsequent examples demonstrate the various deployment decision algorithm operating characteristics and their system performances. We will show that our proposed crash sensing algorithm has been designed to timely and correctly deploy the airbag with regards to the safety issues. It also considers some cost saving aspects. During a crash, the system will not deploy the airbag unnecessarily such as in the case of none occupancy, a detected unsafe distance condition, low severity crashes etc. Basing on Fig, 1, which depicts typical airbag deployment operating characteristics, we have developed an accurate airbag deployment decision algorithm and sensor system design. As shown in Fig. 1, 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 best algorithm will be the one closest to the optimal point of (0, 1).

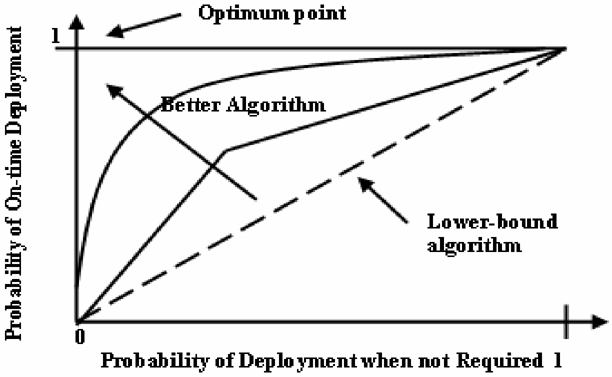

Fig. 1 Airbag deployment operating characteristics

The block diagram of the overall occupant detection and crash sensing system model for frontal collisions is shown in Fig. 2. It consists of three main modules, namely occupant sensing, crash severity analysis and decision fusion modules. The occupant sensing module involves the simulation and algorithms development to detect occupancy, determine correct occupant size and monitors occupant off-position condition to determine safe distance between occupant and the frontal airbag unit. The weight sensor determines the status of seat occupancy and this information is conditioned using a conditional circuit and converted into a digital signal by an analog to digital converter (ADC).

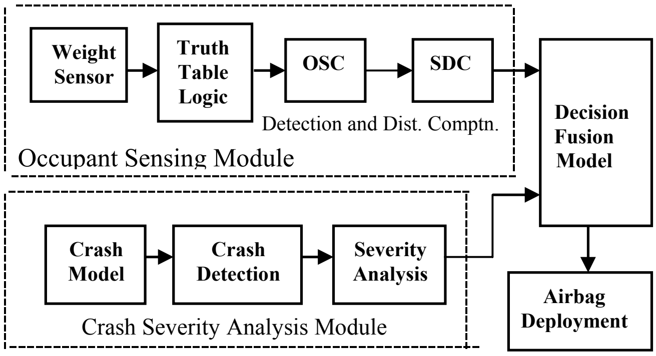

Fig. 2 Overall system block diagram

The output of the digital converter is then passed to the combinatorial logic truth table Boolean parameter to specify occupancy and action. Occupant detection and occupant size classification along with the safe distance computation are carried out using two units of state controllers, namely the occupant sensing controller (OSC) and safe distance controller (SDC). Once occupancy is determined, classification of occupant is configured and the safe distance is computed. Additionally, the crash severity analysis module involves computer simulation of various crash conditions to determine the deployment parameters. Results from these two modules are fused in the decision module to trigger a correct action for airbag deployment.

Integration of these modules forms the occupant and crash sensing system that must operate very quickly so as to inflate the airbag completely within 20 msec from the time when a decision has been made. Detail explanation is given in the subsequent subsections.

A. Occupant Sensing Controller

Fig. 3 illustrates the state flow controller of the OSC that determines the status of seat occupancy as either empty or occupied. The OSC is a sub-module of the occupant sensing module. Once occupancy is detected, the occupant is classified accordingly as either adult or child. The inputs to the occupant sensing controller are the combinatorial logic and a set of weight condition. For example, if an occupant is detected, the controller outputs either a ‘1’ for child or a ‘2’ for adult. Otherwise, the controller outputs a ‘0’, which represents no-occupancy.

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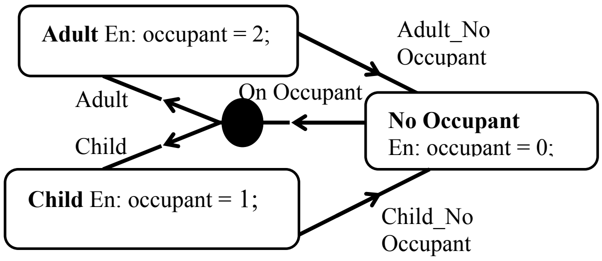

Fig. 3 Occupant sensing state flow controller

B. Safe Distance Controller

The safe distance controller acts upon receiving input from the OSC. Fig. 4 shows the safe distance state flow controller in which safe distance decision is determined by a function of distance condition. A distance condition using the NHTSA '5-10-20' standard rule has been imposed to the SDC.

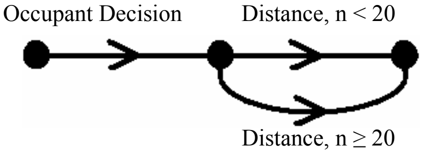

Fig. 4 Occupant sensing state flow controller

Using NHSTA '5-10-20' standard rule, if the distance between the occupant and the airbag unit is less than 20 inches (i.e. $n < 20$) then an output of '0' is marked at the SDC, which implies an unsafe condition for the passenger, and as such, the airbag is not deployed. However, if the distance between the occupant and the airbag unit is equal or greater than 20 inches (i.e. $n \geq 20$), the SDC output is marked as occupied with a decision of either '2' for adult or '1' for child. The SDC also automatically gives an output of '0' when OSC output is '0'. Results from SDC triggers the airbag action, a '0' output implies no deployment while an output of either '1' or '2' means the airbag will deploy.

C. Crash Analysis Parameters

A well-designed 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. 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 vehicle speed, $v(t) = \int a_s(t)\, dt + v0$, where $v0$ is the initial velocity of the vehicle, change in vehicle velocity, $\Delta v = \int a_s(t)dt$, and accelerometer signal, $a_s(t)$. These parameters are described briefly as follows,

1) Vehicle Speed: Vehicle speed is amongst the most important parameters for crash analysis and its modeling development. As aforementioned, a standard airbag unit deploys if the collision force is equivalent to a frontal collision with a stationary barrier at a speed of 22.54 kmph or higher. However, if the collision force is equivalent to a barrier-crash at a speed of 12.88 kmph or less, the airbag should not deploy. If the collision force is neither (i.e. 12.88 kmph < $v(t)$ < 22.54 kmph), 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) Change in Vehicle Velocity (Δv): The change in velocity, Δv is obtained by computing the integration of the acceleration signal. 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. If Δv exceeds the threshold speed (i.e. $\Delta v \geq v_{th}$), then it is certain that the crash has occurred inside the deployment zone, which requires a 'must deploy' decision and therefore, the airbag must be triggered, regardless of the crash type.

3) Vehicle Acceleration: The vehicle acceleration 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 and the noise components. 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 noise component, on the other hand, 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. Under normal circumstances, the signal from the accelerometer produces too much noise if it is located at the soft part of the vehicle, or at the part of the vehicle, which is vulnerable to a crash. To design a good crash sensing system, the accelerometers must be placed at the least noisy location in the vehicle, so that the vehicle acceleration component, $a(t)$, can be easily separated from the accelerometer signal, $a_s(t)$.

III. THE ALGORITHM AND DECISION

In this section, the algorithm for the occupant detection and classification, safe distance decision and crash analysis decision is described. The proposed algorithm mainly consists of three modes, which are described in terms of their object, input, output and the approach used.

A. Occupant Decision Mode (ODM)

The occupant decision-making (ODM) algorithm is implemented using a sequential state flow diagram as shown in Fig. 5. ODM will only activate if occupancy is detected. As such, once occupancy is detected, the occupant weight is sampled and then check whether the measured weight is either $w \geq m$ or $w < m$, where m is the minimum weight of the adult occupant. The following rules are used in decision-making process.

i) If $w \geq m$, *then* output is a ‘2’; DECISION: occupant detected as ‘*adult*’
ii) If $w<m$, *then* output is a ‘1’; DECISION: occupant detected as a ‘*child*’.
iii) If $w=0$, *then* output is a ‘0’; DECISION: no occupant detected

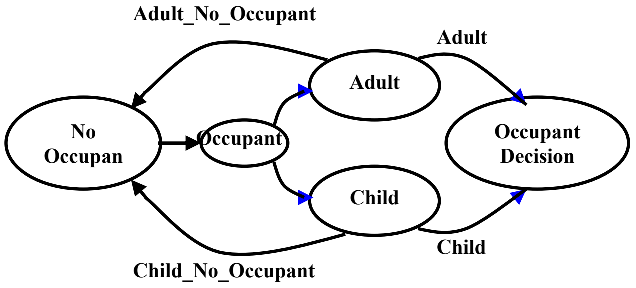

Fig. 5 State diagram of the occupant decision-making

B. Safe Distance Decision Mode

The safe distance deployment of airbag relies on the distance based decision algorithm. The state flow controller approach is again used to provide a conditional numerical measure of safe distance between the occupant and the airbag as shown in Fig. 6, where, d_1 and d_2 are the minimum safe distance from the adult and child occupant to their airbag units, respectively.

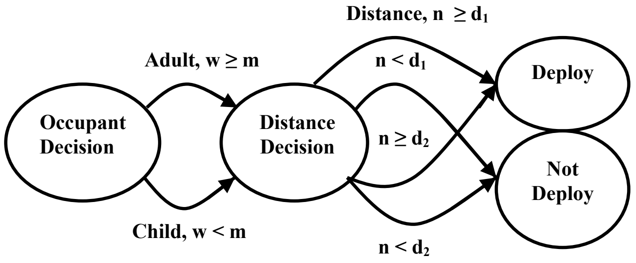

Fig. 6 State diagram of the safe distance decision

The decision-making algorithm is described as follows:

i) Once the occupant decision algorithm gives its decision, the safe distance decision mode is activated.
ii) If the occupant is an adult and the distance, *n*, exceeds d_1 (i.e. $n \geq d_1$), the output is set to ‘1’ and the adult airbag will be deployed.
iii) If the occupant is a child and the distance, *n*, exceeds d_2 (i.e. $n \geq d_2$), the output is also set to ‘1’ but this time the child airbag will be deployed instead.
iv) However, when the safe distance condition is violated (i.e. either *condition ii or iii*) even though the occupant has been detected and identified accordingly, the airbag will not be deployed under normal circumstances.

C. Crash Decision Mode (CDM)

Typically, a crash analysis system involves algorithms development for crash detection, crash severity analysis and airbag deployment decision. The basic algorithm structure composes of three states namely, normal, standby and fire, which are described in terms of their object, input, output and the approach used. For the CDM, a sequential state flow is used. The change in velocity, Δv must first be computed. Then, the following conditions are checked: Is $\Delta v \geq v_{th}$ or $\Delta v < v_{th}$, where v_{th} is the threshold value.

i) If $\Delta v \geq v_{th}$, *then* output is a ‘2’; DECISION: Crash is detected and shift to standby state.
ii) If $\Delta v < v_{th}$, *then* output is a ‘1’; DECISION: No Crash detected and back to normal state.

Next, the speed based decision algorithm is designed to give decision whether or not the airbag is to be deployed. Therefore, the vehicle speed must be determined and compared to the threshold speed of *22.54 kmph*, in which the airbag must be set for deployment if the vehicle speed exceeds the threshold. The procedures are described 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, *s(t) is greater or equal 22.54kmph (i.e. s(t) ≥22.54kmph)*, then output is set to ‘1’ and the airbag will be set to ‘FIRE’ state.
iii) If the crash is detected and the speed, *s(t)<12.88 kmph*, the output is set to ‘0’ which returns it to the ‘STANDBY’ state.
iv) However, if the speed of the vehicle exceeds *12.88 kmph but is less than 22.54 kmph,* then the decision can be set to either ‘FIRE’ or ‘STANDBY’

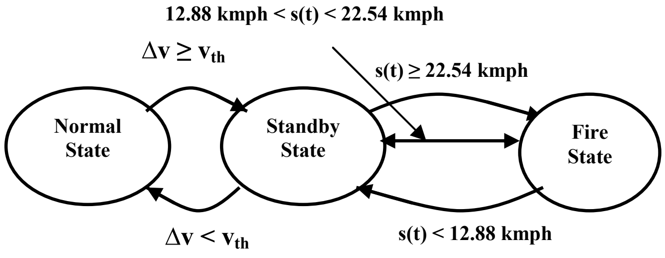

Fig. 7 State diagram of crash decision-making circuit

At the ‘fire’ state, the change of velocity, Δv, over a period of time T can be computed by integrating either s(t) or a(t) signal. Assuming that the accelerometer is placed at the noise free location, the integral over the noise component will be approximately zero i.e.,

$$\begin{aligned}\Delta v &= \int_0^T a_s(t)\ dt \\ &= \int_0^T a(t)\ dt + \int_0^T n(t)\ dt = \int_0^T a(t)\ dt \qquad (2)\end{aligned}$$

The circuits for computing Δv can be designed using the systolic architecture to achieve a real-time speed. The outputs from this fire state are fed into a state flow circuit, which will then make the airbag deployment decision. This decision-making circuit can be implemented as a synchronous sequential machine with only three states: NORMAL, STAND-BY and FIRE, which have been defined earlier. The state diagram of this sequential machine is shown in Fig. 7.

IV. RESULTS AND DISCUSSIONS

The proposed model of an intelligent crash sensing system for airbag deployment comprising of the occupant detection and classification, safe distance decision, deployment decision and crash severity analysis algorithm is analyzed using Simulink, Stateflow, Sim-Mechanics and Virtual Reality of Matlab tools.

Fig.8 shows the simulation results for the case of a child occupant. Upon detecting the crash, the occupant detection process took about 20.6 msec whilst the deployment action took 18.4 msec. It is also noted that during the crash involving a child occupant, the airbag detection system gained a huge force of ~ 9000 N/m as shown in Fig. 9. This amount of force is being released when the airbag is deployed.

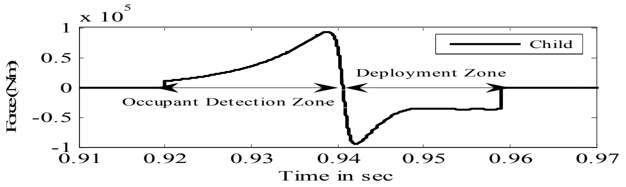

Fig. 8 Occupant detection and airbag deployment zone

The significant of adult versus child airbag deployment is shown in Fig. 9. During a crash, an adult airbag unit will gain twice the amount of force compared to the child airbag unit due to differences in the size of airbag. The total airbag detection and deployment durations for the adult unit are longer compares to the child unit.

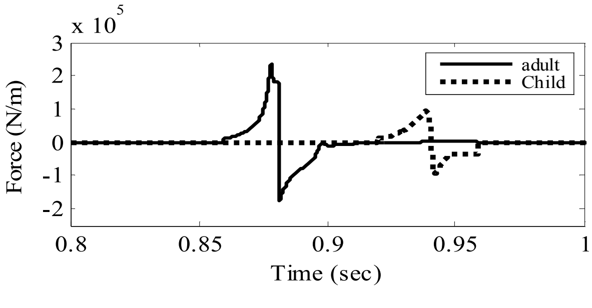

Fig. 9 Occupant detection and airbag deployment of adult and child

For the adult case, the occupant detection and deployment actions lasted for 21.5 ms and 18.5 ms, respectively. Whilst for the child case, the reaction time to detect and deploy are 20.6 ms and 18.4 ms, respectively. However, the time to actuate the child airbag unit starts somewhat later at time 0.92 msec compared to the adult unit that starts at 0.86 msec. As such, our results suggest that in a crash involving adult the detection and deployment action occurs earlier and lasted longer when compared to that of a child occupant case.

The airbag size also plays an important role to ensure sufficient protection to the occupant whether it is adult or child. Fig. 10 shows the simulation results for the airbag experiments from the airbag size point of view. Referring to Fig. 10 (a) and (b), the adult airbag size is much bigger than that of the child airbag unit. The results also showed that the airbag unit has deployed correctly acting upon the decision produced. For instance, in Fig. 10(a) the occupant detection algorithm correctly deployed the airbag for adult when it detected an adult occupant while the child airbag remained intact. However, when a child occupant is detected, the child airbag is deployed and not the adult as shown in Fig. 10(b). Fig. 10(c) depicts the comparison in terms of airbag deployment time for both the adult and child airbags.

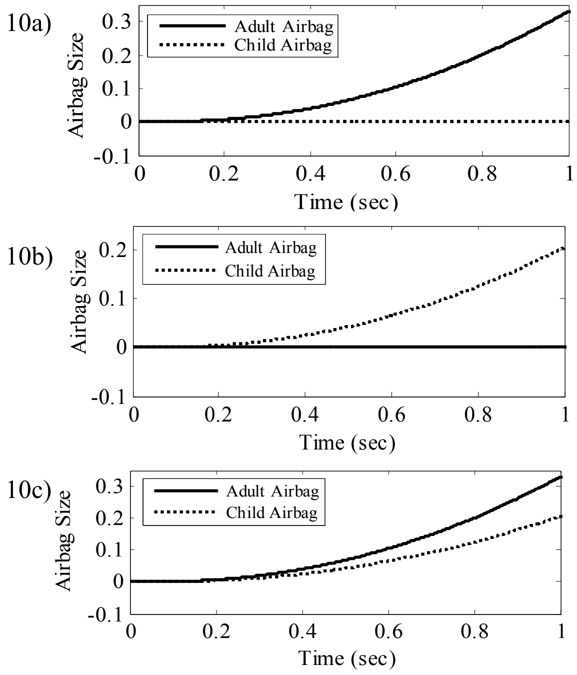

Fig. 10 Adult and child airbag size for deployment

Shown in Fig. 11 are the simulated results obtained in terms of acceleration, velocity and displacement. Fig. 11(a), (b), (c) and (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 when the speed is equal or exceeds 22.54 km/h (or 14m/h). As shown in Fig. 11(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 Fig. 11(b), (c) and (d), the airbag is deployed since the speed in all three cases is either greater or equal 22.54 km/h. In Fig. 11(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.

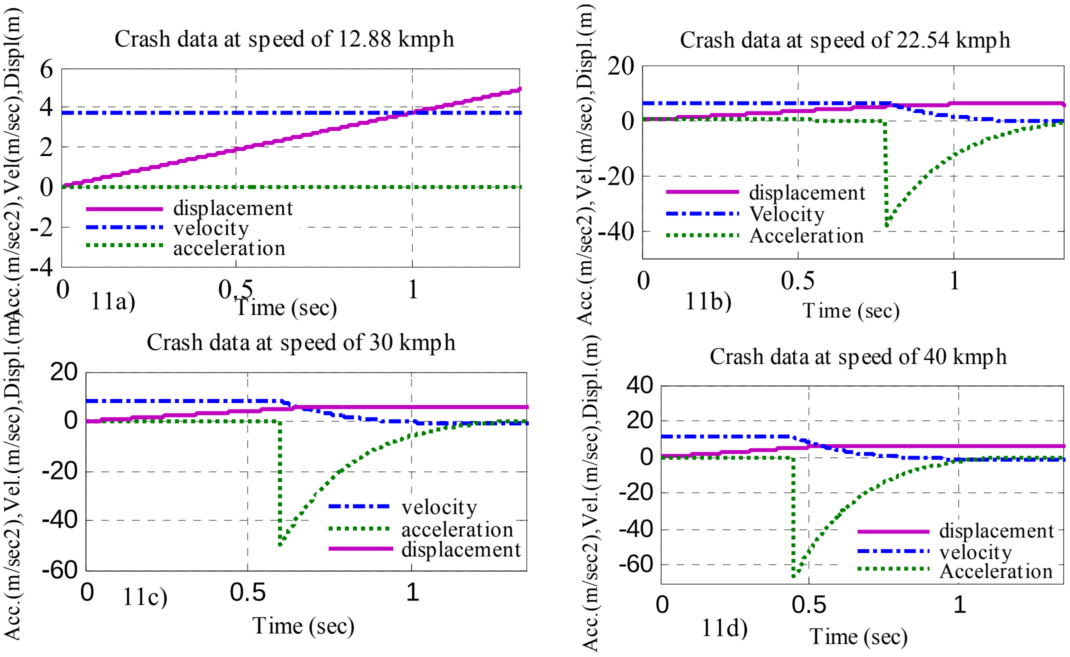

Fig. 11 Crash data results at various speeds

Similarly, the airbag unit 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. These results imply 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. Fig. 11(b), (c) and (d) represent the crash data results at the speed of 22.54 kmph, 30 kmph & 40 kmph, respectively. Additionally, it can be concluded that deceleration is a good parameter to determine crash severity and thus provide a good decision for airbag deployment/non deployment action at the time of crash.

Fig. 12 shows the curves for the various changes in vehicle velocity, Δv, representing five different simulated crashes. The Δv parameter is used to determine the condition for triggering the airbag. A constant value of the vehicle speed was chosen as threshold, v_{th}=5 m/sec.

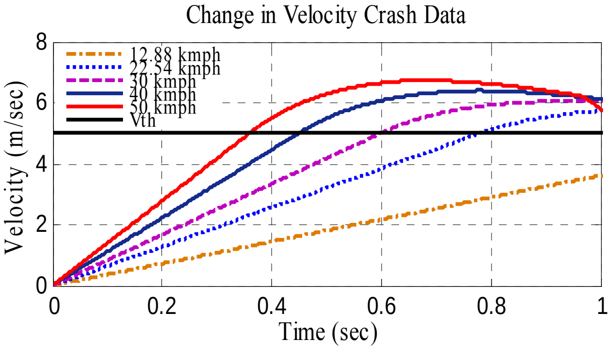

Fig. 12 Crash detection with changing velocity of the vehicle during crash

Our simulation results showed that the airbag was not deployed for the 12.88 km/h crash, since its change in velocity does not exceed the threshold value that warrants for an airbag deployment. But when Δv exceeds v_{th} (i.e. $\Delta v \geq v_{th}$), the airbag was deployed. Fig. 12 shows four other crash scenarios involving the 22.54km/h, 30km/h, 40km/h and 50km/h crashes, respectively. The x coordinates of the crossings between the various curves and the threshold represents the airbag deployment time. The deployment time 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. These results suggest that speed has direct impact on airbag deployment time. In short, the faster the speed, the earlier the deployment will be since faster speed will result in greater collision impact.

It was mentioned earlier that the acceleration signal also contains vital information about the crash. Fig. 13 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.

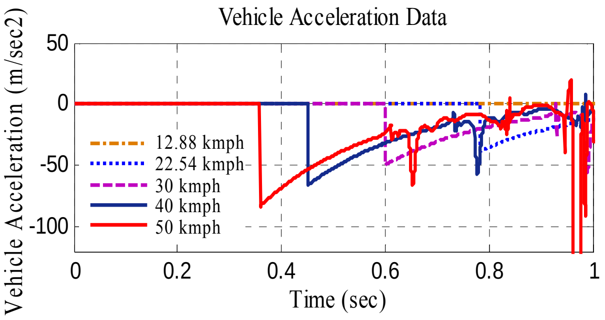

Fig. 13 Vehicle acceleration Crash data at various speeds

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 Fig. 13. 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 was measured for various crashes. The results are shown in Fig. 14. It can be seen that during airbag deployment for the various crash conditions, the compression forces are different. The compression force output depends on severity of the crash. 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 huge forces of between ~4000 N/m to ~15000 N/m and these forces are released when the airbag is being deployed. Fig. 14 depicts the various airbag compression forces being released for the various crash conditions simulated.

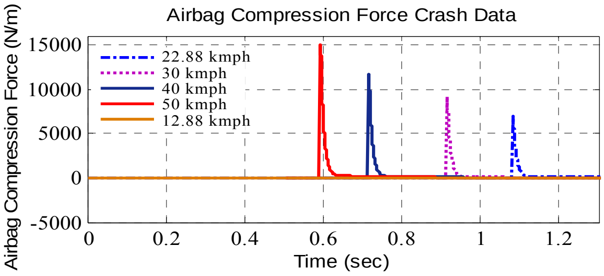

Fig. 14 Airbag compression force during various crashes

V. CONCLUSION

This paper describes a simple but functional algorithm that has been used to develop a crash sensing system model for frontal collision. The system is to be used in an airbag system that incorporates intelligence and deploys only if necessary. The occupant detection and classification was based on weight and combinatorial logic while the safe distance measure follows the NHTSA standard rule. Three main parameters were used and the parameters are change in vehicle velocity, vehicle speed and vehicle acceleration. Change in velocity is used to detect crash, vehicle speed is used to determine airbag deployment decision and acceleration information determines the crash severity.

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 occupant and its size, maintain the safe distance, make timely and correct airbag deployment decision and provide information about the severity of the crash. In conclusion, this study has proven that at higher 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 faster and amount of force release will be higher.

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REFERENCE

[1] M. Devy, A. Giralt, and A. Marin-Hernandez, "Detection and Classification of Passenger Seat Occupancy using Stereovision", *Proc. of the IEEE Intelligent Vehicle Symposium,* Dearborn (MI), USA, Oct. 3-5, 2000, pp. 714-719.

[2] H. Kong, Q. Sun, ,W. Bauson, S. Kiselewich, P. Ainslie, and R. Hammoud, "Disparity Based Image Segmentation for Occupant Classification", *Proc. of the IEEE Computer Society Conf. on Computer Vision and Pattern Recognition Workshops* (CVPRW04), 2004, pp.126-133

[3] J. Krumm, and G. Kirk, "Video Occupant Detection for airbag Deployment*", Proc. of the Fourth IEEE Workshop on Applications of Computer Vision (WACV '98*), 19-21 Oct. 1998, pp. 30 – 35.

[4] S. Enouen, D. A. Guenther, & T. F. MacLaughlin, "Comparison of Models Simulating Occupant Response with Airbags", *SAE Trans.* Section 3, 840451, pp. 343-358, 1984.

[5] R. Brantman, and D. Breed, "Use of the Computer Simulation in Evaluating Airbag System Performance", *SAE Trans.* Section 4, 851188, pp. 1072-1081, 1985.

[6] K. Watanabe, and Y. Umezawa, "Optimal Triggering of an Airbag" *Proc. of the IEEE Intelligent Vehicles '93 Symposium*, 14-16 July, 1993, pp. 78-83.

[7] S. Gautama, S. Lacorix, and, M. Devy , "Evaluation of Stereo Matching Algorithms for Occupant Detection", *Proc. of the International Workshop on Recognition, Analysis, and Tracking of Faces and Gestures in Real-Time Systems,* 26-27 Sept. 1999, pp. 177-184.

[8] M. E. Farmer, and A.K. Jain, "Integrated Segmentation and Classification for Automotive Airbag Suppression". *Proc. of the IEEE Int. Conf. on Image Processing, 1*4-17 Sept. 2003, 3, pp. 1053-1056.

[9] D. Chaikin, "*Airbags" Popular Mechanics",* pp. 81, 1991.

[10] S. B. David, S. Lori, J. Carlson, and M. Koyzreff, "Development of an Occupant Position Sensor System to Improve Frontal Crash Protection", *Proc. of the 18 th International Technical Conf. on the Enhanced Safety of Vehicles (ESV),* Paper No. 325, Paris, 2001.

[11] C-Y. Chan, "On the Detection of Vehicular Crashes—System Characteristics and Architecture", *IEEE Transaction on Vehicular Technology,* Vol. 51, No. 1, pp. 80-193, 2002,

[12] C-Y. Chan, "A Treatise on Crash Sensing for Automotive Air Bag Systems", *IEEE/ASME Transaction on Mechatronics*, Vol. 7, No. 5, pp. 220-234, 2002.

[13] G. W. McIver, "Method and apparatus for sensing a vehicle crash condition using velocity enhanced acceleration crash metrics," U.S. Patent 5 587 906 (1996).

[14] R. Shaw, and J. Onder, "Emergency Rescue Guidelines for Air Bag Equipped Vehicles", *National Highway Traffic Safety Administration (NHTSA),*http://www.emergencygrapevine.com/vl0102/ergair.htm, (2002).