# DEVELOPMENT OF A DECISION MAKING ALGORITHM FOR AIRBAG CONTROL

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*Abstract*: Recently, many algorithms have been developed for airbag system to reduce head injury during the crash. Most of these algorithms are based on a single-point electronic accelerometer placed in the passenger compartment. This accelerometer is expected to overcome the limitations of the current distributed mechanical sensors which is costly and ineffective to trigger the airbag on time for different types of crashes. The electronic sensor is more effective in the sense that the signal from the accelerometer can be digitized and analyzed to study the behavior of the signal for different types of crashes. Unfortunately, most of the algorithms which are based on a single-point accelerometer still have several problems, they fail to trigger the airbag on time for several types of high speed crashes such as pole and angle crashes, or if they do trigger at these crashes they will also trigger at low speed barrier crashes [3],[5],[6]. Some of these algorithms study the first and second integral of the signal to get the change in vehicle velocity and the change in occupant position with respect to the car, other algorithms first filter the signal at a random low cutoff frequency and make different analyses [1],[4]. This paper presents a new algorithm for airbag control. In order to develop the algorithm first we analyzed the unfiltered accelerometer signal in time domain, then we studied the frequency response of the signal and analyzed its components and their effects on the signal. After that we studied the filtered accelerometer signal in time domain, and finally we developed an algorithm based on our observation.

## I. INTRODUCTION

Previous methods use different parameters to detect the severity of the crash. Some of these parameters are derived directly from the accelerometer signal. Here we list the basic parameters which we investigated to detect the severity of the crash:

- The signal itself $s(t)$, which is the acceleration of the vehicle
- The absolute value of the signal $s(t)$
- Change in vehicle velocity $\Delta v = \int s(t)dt$
- The integral of the absolute value of the signal $\int s(t)\ dt$
- The derivative of the signal $ds(t)/dt$
- The integral of the absolute value of the derivative $\int |ds(t)/dt| dt$
- Number of oscillation per unit time

We consider these parameters as the basic parameters because any other parameter which is a monotonically increasing function or the integral of a monotonically increasing function of the above parameters will not discriminate between different types of crashes if the basic parameters did not. This will save us time by not looking at many parameters such as the energy in the signal $\int s(t)^2 dt$ which is the integral of a monotonically increasing function of $|s(t)|$.

An important parameter that discriminates between all different types of crashes, is the change in vehicle energy (note that it is different from the energy in the signal) which can be computed as follows

$$\Delta E = \int m \cdot s(t) \cdot v(t) dt \tag{1}$$

*Where* $v(t) = \int s(t)dt + v_O$, and $m$ is the vehicle mass. If we assume $m$ to be equal to 1, then the above parameter is the energy per unit mass. However, there are several problems in using the change in car energy. This parameter requires to keep an eye on the initial velocity $v_O$ at the beginning of the crash, and it changes significantly for the same change in car velocity ($\Delta v$) at different initial velocity ($v_O$), i.e. if the car speed changes from 10mph to 0mph then the value of $\Delta E$ will be much less than if the car speed changes from 20mph to 10mph. Note that in both cases the severity of the crash to the occupant is the same, therefore we should avoid any parameter which depends on $v_O$.

From the time domain analysis of the unfiltered signal we found that only the change in velocity is enough to determine whether or not to fire the airbag in case of frontal barrier crash. But we could not find any parameter which discriminates between all different types of crashes (pole, offset, angle) unless the initial velocity $v_O$ is used.

## II. THE SIGNAL WAVEFORM

There is no doubt that during a crash the car is slowing at a certain rate given by $s(t)$. Some authors modeled $s(t)$ by a haversine pulse which has a low frequency components (0-10Hz) [1],[4]. They consider the remaining part of the signal as the noise part which comes from the deformation and vibration of the vehicle. So they filter the signal at 10Hz to investigate several parameters such as the first derivative of $s(t)$ (Jerk) [2], the energy in $s(t)$ and the energy in the remaining components [4].

We believe that filtering the signal down to 10Hz will not only eliminate or average some of the important pulses in the signal, but also will incur a long time delay in the filtered signal which could be longer than the firing time.

It is important to study the whole slowing components which contains pulses at moderate frequency due to several distributed solid objects in the car (bumper, motor, radiator,..). These pulses are very important to measure the intensity of a crash. A higher speed crash causes a higher frequency and amplitude pulses than a lower speed crash.

To analyze the slowing component $a(t)$ we took several accelerometer readings for the same crash at different locations in the vehicle. We found that different accelerometer locations yield to different signals. There are three reasons for that. First, the accelerometer measures the slowing of that part of the vehicle where it is located: an accelerometer placed in the front of the vehicle will give higher values than an accelerometer placed in the passenger compartment or at the end of the vehicle. Second, each part of the vehicle vibrate at different frequency, and there are several locations which oscillate at low frequencies that may overlap with the slowing components. Third, the way the accelerometer is mounted at that location: if the accelerometer is loosely fixed in the vehicle, it will shake and vibrate at a frequency which could overlap with the slowing component. Figure 1 represents the frequency response of the slowing components $A(f)$ and the oscillating components $O(f)$. Figure 2 shows two



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accelerometer signals and their corresponding frequency responses at two different locations for the same crash: (a) The location oscillate at a low frequency, (b) the location oscillate at a high frequency.

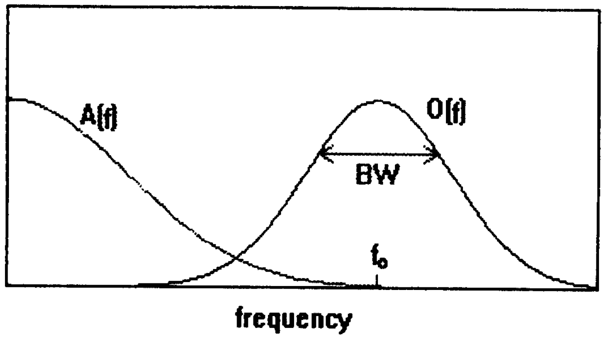


**Figure 1**. The frequency response of slowing signal a(t) and the oscillating part o(t).

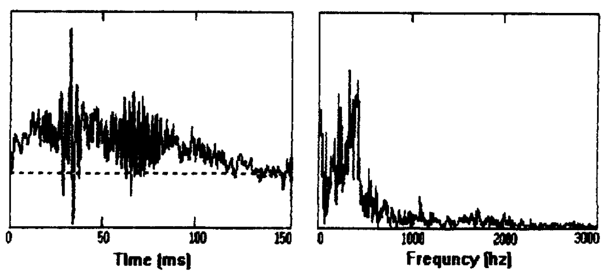


**Figure 2a**. The location oscillate at low frequency.

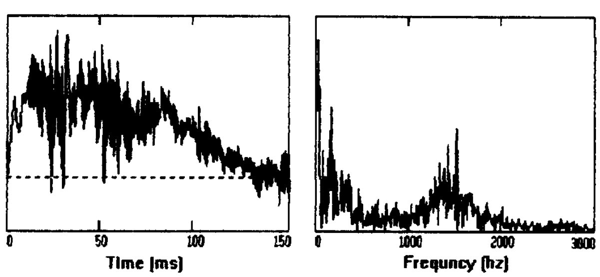


**Figure 2b**. The location oscillate at high frequency.

From Figure 1 it is clear that in order to separate the slowing part $a(t)$ from the oscillation part $o(t)$, $O(f)$ must be in the high frequency range and has low frequency bandwidth *(i.e. high quality factor)*. It is obvious that we can discriminate between these two parts at the location which has an accelerometer signal shown in Figure 2b, but it is impossible to do this at the location in Figure 2a.

## III. FILTERING

To obtain the slowing components alone, the signal must be filtered at certain cutoff frequency. This cutoff frequency is determined by the location of the accelerometer as explained earlier. We found that an accelerometer located at the *left or right-rocker @ B-pillar* requires a filter with cutoff frequency of 500Hz. Note that filtering at 500Hz will incur about 2ms time delay only. We filter the signal at 500Hz to analyze the slowing part. We found the following from the filtered signal:

1. The change in velocity is almost the same whether it is calculated from the original signal or from the filtered signal, this is because the integration of the oscillation component $o(t)$ over a period of time is close to zero.

$$s(t) = a(t) + o(t) \tag{2}$$

$$\begin{aligned} \int s(t) &= \int a(t)dt + \int o(t)dt \\ &= \int a(t)dt + 0 \\ &= \int a(t)dt \end{aligned} \tag{3}$$

The following figure represents the oscillation component over a period of time. It is clear that the area under this curve is close to zero.

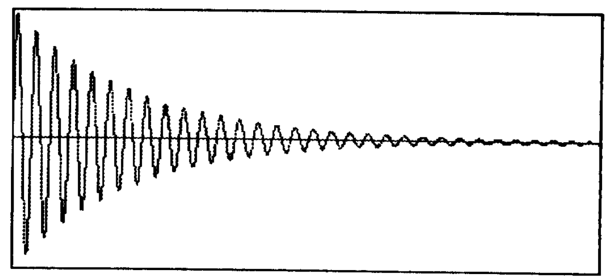

**Figure 3**. Oscillation

2. There are more swings in $a(t)$ in crashes which affect part of the front surface of the car (pole crash) than those crashes where the whole surface is affected (barrier crashes), The reason for this fact is that for pole crash, the pole penetrates more through the car than the barrier does which means that it faces more changes due to the different distributed objects in the car. These changes are reflected as pulses in the signal.
3. To have a quantitative measure which is a monotonically increasing function through the crash for these swings, we use two different techniques, the energy in the first derivative of $a(t)$ (energy in the jerk) and the curve length of $a(t)$.

$$\textit{Curve length} = \int \sqrt{\left(\frac{da(t)}{dt}\right)^2 + 1}\; dt \tag{4}$$

$$\textit{Energy in the jerk} = \int \left(\frac{da(t)}{dt}\right)^2 dt \tag{5}$$

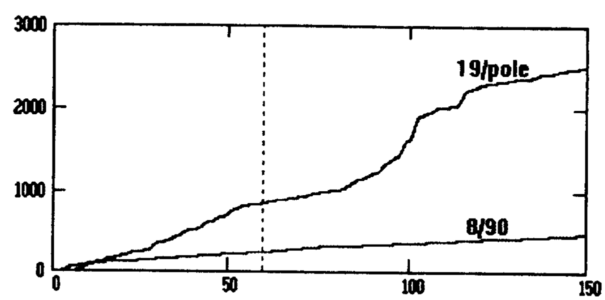


**Figure 4**. The curve length of the filtered signal

We chose the curve length as our measure because it has lower data variance for similar crashes. Figure 4 shows the curve length for an 8mph barrier crash and 19mph pole crash. Figure 5 shows the corresponding change in velocity. Note that while the change in velocity fails to discriminate between 8/90 and 19/pole crashes the curve length does not fail.

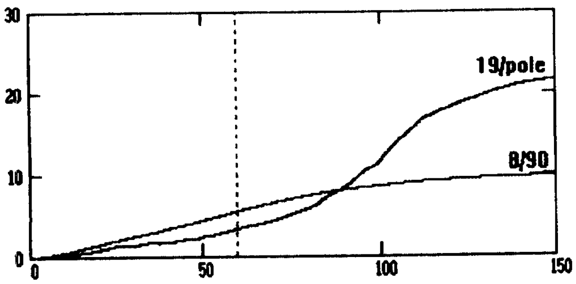


**Figure 5**. Change in velocity

## IV. TIMING

Normally the airbag is deployed if the collision force is equivalent to a frontal collision with a stationary barrier *(barrier crash)* at a speed of 14mph or higher. The greater the collision impact the earlier the airbag should be deployed. If the barrier crash occurs at a speed of 8mph or less, the airbag must not be deployed.

So far we found that there are two parameters which can be used to discriminate between crashes. The first one is the change in vehicle velocity which can be used to discriminate between all barrier crashes. The second one is the curve length which can be used to discriminate between crashes where only a part of the vehicle surface is affected. Thus, if we want to discriminate between all barrier crashes, we can use the first parameter in our algorithm. Unfortunately, this is not completely true because a threshold on the change in velocity which must be achieved to fire the airbag on time for the 14mph crash may also be achieved later by a non-firing crash as shown on figure 6.

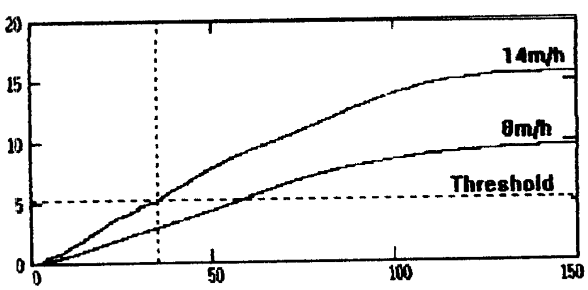


**Figure 6**. Change in velocity. 8mph and 14mph barrier crashes

Due to this problem we decided to measure the change in velocity within a 35ms sliding window. The reason we chose 35ms window is that it is the average firing time for the minimum barrier crash speed which requires airbag deployment. Figure 7 shows the change in velocity (measured using a sliding window) for 14 and 8mph barrier crashes. This figure shows that for an 8mph barrier crash the change in velocity does not reach the threshold value for airbag deployment. Thus, the sliding window technique for measuring parameters is effective.

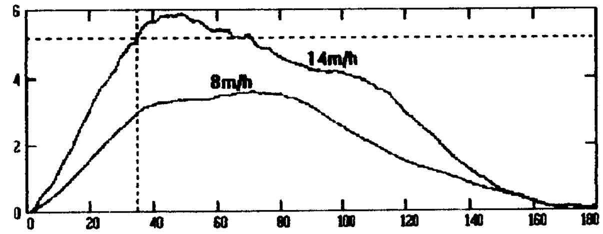


**Figure 7**. The value at time t is the change in velocity during the last 35ms

There are several techniques to implement the sliding window, one of them is shown in Figure 8.

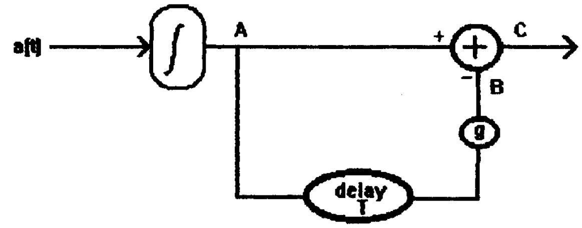


**Figure 8**. Hardware implementation of a sliding window to compute the change in velocity.

The signal at point A is the change in velocity at time t, while the signal at point B is the change in velocity at time T ms earlier. If g=1 then the output at point C is the change in velocity within the last T ms.

$$\Delta v_A = v_A - v_0 \tag{6}$$

$$\Delta v_B = v_A - v_0 \tag{7}$$

$$\begin{aligned} \Delta v_A - \Delta v_B &= v_A - v_0 - (v_B - v_0) \\ &= v_A - v_B \end{aligned} \tag{8}$$

A similar technique can be used to compute different parameter within a certain time period. The only thing to be changed in Figure 8 is to replace the integrator by the desired function.

## V. THE ALGORITHM

From the previous discussion we can samurais our observations as follows:

1. For all barrier crashes where the whole surface of the car is facing the crash, the change in vehicle velocity within a certain period of time is a good measure to discriminate between these crashes.
2. The change in velocity must be computed from the most recent $T_1$ ms samples, where $T_1$ is the firing time for the minimum speed barrier crash where airbag deployment is necessary. The time $T_1$ depends on the structure of the vehicle, vehicles with hard bumper will have lower value of $T_1$, so we could have different values of $T_1$ for different types of vehicles.
3. For crashes where a part of the front surface of the vehicle is affected, we found that the curve length of the filtered accelerometer signal is a good measure to discriminate

between these crashes.

4. Similarly, as we did in the change in velocity case, we measured the curve length from the most recent $T_2$ms samples. Here $T_2$ is the firing time for the minimum speed of other cases. Normally $T_2 > T_1$.
5. In Rough road data where we could have a high value of the curve length, we found that the change in velocity is small compare to all different type of crashes where airbag is necessary. This will introduce two thresholds on $\Delta v$, $V_1$ which discriminates between rough road data and crash data, and $V_2$ which discriminates between the severity of barrier crashes. Of course $V_2 > V_1$.
6. Unfortunately, due to the cost of the crash test, we are unable to have sufficient data for the same type of car to build a good classifier using the pattern recognition techniques which will discriminate between firing and non-firing crashes. However, the following state diagram is good enough to discriminate between most cases.

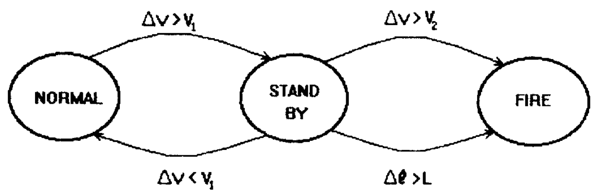


**Figure 9.**

7. The algorithm will be in the *stand by* state if a certain threshold on $\Delta v$ is obtained. This threshold must be high enough to discriminate between rough road data and crash data. The value of this threshold depends on the structure of the vehicle, a vehicle with harder bumper will have higher $V_1$, and hence a better algorithm. Note that a high value of curve length must be associated with a certain value of $\Delta v > V_1$ to go to the fire state.

The following table shows the simulated results for the same sensor location, note that it is important to maintain the same sensor location specially if the curve length is concerned. As we can see from the table that most of the requirement is met.

| CRASH MOD | REQUIREMENT | ALGORITHM |
|---|---|---|
| 8/90 | NF | NF |
| 8/90 | NF | NF |
| 19/POLE | 57 | 31 |
| 19/POLE | 63 | 49 |
| 19/POLE | 59 | 57 |
| 14/90 | 44 | 40 |
| 14/90 | 32 | 30 |
| 31/90 | 22 | 22 |
| 31/90 | 22 | 22 |
| 17/POLE | 56 | 55 |
| 31/POLE | 32 | 26 |
| 22/30$^o$L | 52 | 53 |
| 31/BOR | 47 | 33 |
| 31/L/CTC | 60 | 40 |
| 14/90 | 35 | 31 |

## VI. CONCLUSIONS

A new method for airbag control has been developed. This method uses two different parameters to predict the severity of the crash. The first parameter is the change in vehicle velocity which is used to discriminate between barrier crashes. The second parameter is the length of the filtered accelerometer signal curve which is used to discriminate between all other cases. We tested our algorithm on several crash data and we found that the results are very close to the requirement.

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