Signal Processing for Automotive Applications

Tony Gioutsos

Artistic Analytical Methods, Inc.

Brighton, MI 48116 USA

ABSTRACT

In recent years, the complexity of automobiles has increased sharply. Consumer demands for better performance at a low cost have caused a boom in electrical components. Many of these components require the use of signal processing techniques to provide the desired response. In this paper, we discuss signal processing for use in "smart" sensor design for automotive applications. The paper begins with a general overview of the automotive signal processing environment. It then describes a general framework for algorithm design and performance measurement. Finally, two examples of automotive algorithm design are presented: vehicle crash detection for airbag deployment and engine cylinder misfire detection to reduce environmental emissions.

1. INTRODUCTION

In recent years, the complexity of automobiles has increased sharply. Consumer demands for better performance at a low cost has caused a boom in electronic components. Current vehicles contain hundreds of electrical components. Many of these components require the use of signal processing techniques to provide the desired response. In this paper, we discuss signal processing for use in "smart" sensor design in automotive applications.

The paper begins with a brief description of the typical automobile smart sensor design constraints. These include cost, size, weight, correlation to the physics of the problem, uncertainty in environment, etc.

A modeling and algorithm design approach for signal waveform data is then discussed. This approach borrows heavily from work in the communication, estimation & detection and signal processing fields. The approach is to assume that the system and associated signal waveforms vary in a statistical manner. Prior to this approach, algorithms for automotive applications were designed without a model or statistical variation assumption.

This generic approach to algorithm design and modeling for automotive signal waveforms is discussed in exemplary fashion for two smart sensor applications: Vehicle crash detection and Engine Cylinder Misfire Detection. Overviews for each problem and their algorithm and modeling approaches are discussed.

2. THE AUTOMOTIVE SIGNAL PROCESSING ENVIRONMENT

The automotive environment is one that is very different than most other areas that use signal processing approaches. Two reasons exist for this difference. First, is cost and volume of sales. A one dollar savings for an automotive system is important because of the volume of sales. Therefore, all sub-systems within the vehicle are constrained heavily by cost. This difference is most notably in comparison to signal processing approaches for aerospace, defense and generic R&D applications. The second more important difference is the amount of features that a vehicle must provide to the consumer at a reasonable cost. This makes this product unlike any other. All of the features must be coordinated and cost constrained to provide satisfaction to each consumer. This makes this product unlike a washing machine, TV or a computer. Those products perform basically one function and cost far less.

Therefore when dealing with signal processing algorithms, the automotive industry has been gradual in their acceptance. Microprocessors with high cost are not desired. As an example which we will discuss, a current algorithm for vehicle crash detection was implemented using about one-third of a Motorola HC5 microcontroller, without multiplies, using very little RAM and ROM.

Another difference between the automotive environment and general signal processing environments is the amount of information about the problem at hand. This is a key difference that is best expressed by quoting Gardner [1]: "Many – but by no means all – real-world problems in communications engineering and signal processing involve time-series data for which no population exists; that is, data for which replication of the experiment is impossible or impractical." To obtain enough data to create a "population" for vehicle crashes is expensive and impossible. Therefore, when dealing with automotive signal processing problems, one must always make assumptions based on physics, intuition and experience.

This leads the automotive algorithm and modeling designer to merge signal processing and

0-7803-2431-5/95 $4.00 © 1995 IEEE

information theory techniques with physics through artistically chosen approaches. A neural network approach, for example, can provide an excellent solution to a small set of vehicle crash waveforms. But the real question that the designer must answer is: "How will this system work in the real-world where there are an infinite number of crash waveforms that can occur that were never encountered before?"

Hence, the designing of automotive signal processing solutions is not so much based on theory, but on the creative use of signal processing mathematics in conjunction with physical theory.

3. ALGORITHM AND MODELING APPROACH

In this section, a modeling and algorithm design approach for signal waveform data is discussed. This approach borrows heavily from work in the communication, estimation & detection and signal processing fields. The approach is to assume that the system and associated signal waveforms vary in a statistical manner. Prior to this approach, algorithms for automotive applications were designed without a model or statistical variation assumption.

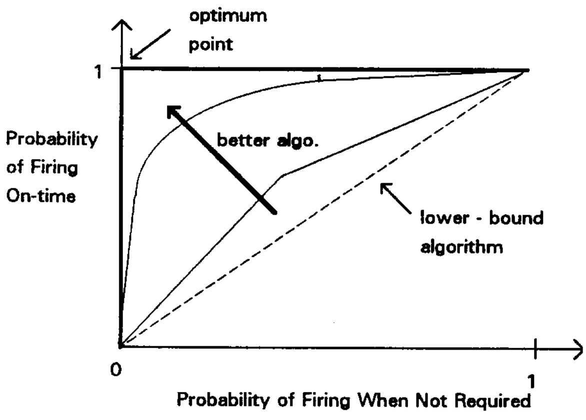

Figure 1 : Crash Detector Operating Characteristic (CDOC)

With a statistical model, Monte Carlo techniques can be used to produce Detector Operating Characteristics (DOC) curves for various algorithm designs. A typical example is depicted in figure 1. This example shows the Crash Detector Operating Characteristic (CDOC) first introduced in [2]. This curve quantitatively depicts the performance of an algorithm or sensor system designed to detect severe crashes on-time for deployment of an airbag, while not deploying the airbag for small crashes, rough road events, and other events.

Curves of this sort can also be generated for any automobile sensor detection problem. Another such example of this is a Misfire Detector Operating Characteristic (MDOC). This curve depicts the tradeoff of a sensor system/algorithm for the correct detection of an engine cylinder misfire.

With a quantitative measure of performance, an iterative technique can be used to provide desired sensor system/algorithm performance. Figure 2 depicts this scenario. An algorithm/calibration design is developed. The performance is then measured using a Monte Carlo approach. If the performance is good, the design is finished. Otherwise, the algorithm/calibration is changed until the desired performance is reached.

4. VEHICLE CRASH DETECTION

In recent years, sensors to determine vehicle crash severity have increased in volume. Originally all of these sensors were mechanical devices placed near the front of the vehicle (see [3] or [4] for an overview). If hit hard enough, they would cause the airbag to deploy. Several reasons have now led to an increased interest in using an electronic single point sensor in the passenger compartment. These reasons are summarized in [5]. They include cost, size, reliability, performance, modeling, adaptability, etc.

The basic approach behind a single point sensor is to convert analog accelerometer data to digital format. This data is then run through an "algorithm" that determines if a severe crash is at hand. If it is, the algorithm deploys the airbag(s). It seems like a simple task, however, it is not.

Many companies have single point sensor systems, some of which are described in [6] - [8]. Currently, very few vehicles contain single point sensors mainly due to inadequate algorithm designs. In [9], an algorithm design is outlined that is currently in production. This approach has been proven in various "crash-offs" (these are vehicle crash tests where suppliers provide single point modules to an automobile manufacturer and the manufacturer then crashes vehicles to see how they perform) to perform in a superior fashion to other algorithm designs.

In [9], signal processing techniques are used in an artistic manner to provide a solution with physical foundation. Figure 3 depicts three crash waveforms. A rough road event, a 9 MPH Frontal barrier crash and a 30 MPH pole crash. The first two events must not trigger the airbag. The last event must trigger the airbag before 35 msec of the crash has elasped. It is not a simple task to separate the 3 events in the depicted acceleration domain. Many of the algorithm approaches to date have used velocity (integration of the acceleration data with an ambiguous start/stop of the accumulator) to help distinguish the differences. This is a nice crash detection "measure" but does not easily help to distinguish the differences in a timely manner. Figure 4 depicts the velocity values of the three crashes over time.

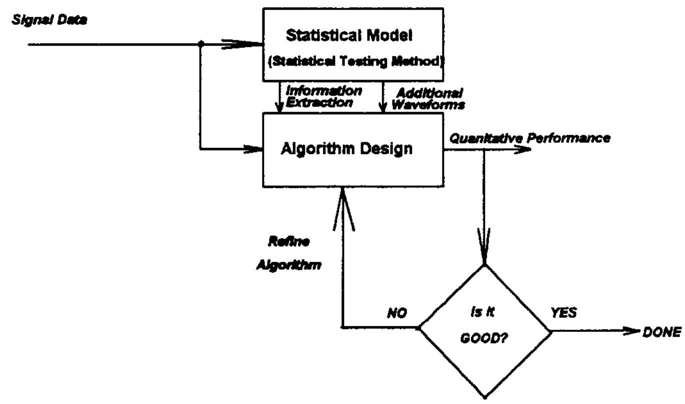

Figure 2 : Iterative Design Approach

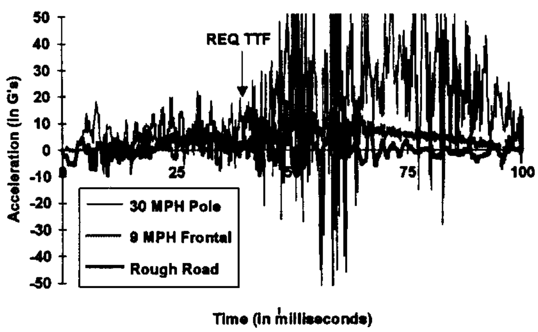

Figure 3: Vehicle Crash Waveforms

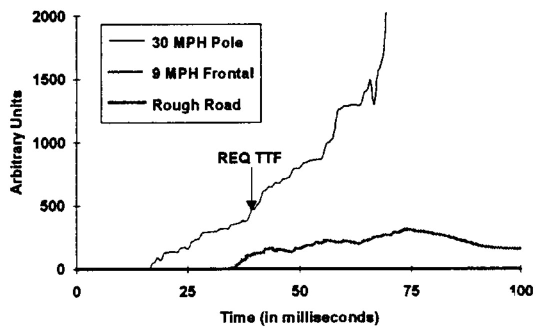

Figure 5: Artistically Created Measure for the Waveforms of figure 3

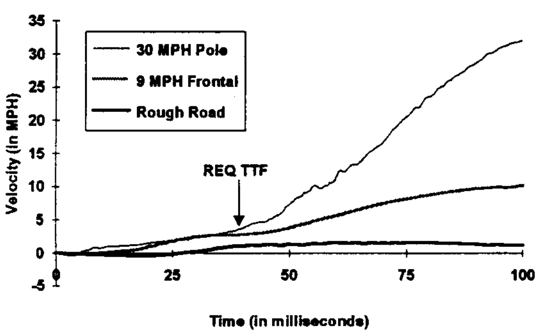

Figure 4: Change in Velocity for the Waveforms of figure 3 (accumulated from time = 0)

Note that there is a small gap between the velocity waveforms, but this gap varies with time. That is, had the waveforms not been plotted relative to each crash's starting point (0 on the time axis), then the 9 MPH Frontal Barrier crash would have a value greater than the pole crash (i.e. slide the velocity waveform). This is one of the biggest dilemmas in the crash detection problem: When does a crash begin? Any assumption of the beginning will cause an algorithm to work improperly in the real world. [9] has solved this problem in a simple fashion. Figure 5 depicts one of the measures from [9] that depicts the ease of separation between the three events even with any time shift.

In [10], a description of the vehicle crash waveform modeling approach is given. The model from [10] helped in algorithm design and performance quantification. The overall design methodology was described in section 3. The modeling technique generated thousands of new crash waveforms (i.e. using a Monte Carlo approach) that could verify performance of the designed algorithm. This approach, although common to the communication field, was the first such effort within the automotive signal processing field, and it produced excellent results.

4. ENGINE CYLINDER MISFIRE DETECTION

The goal in this application is to detect many engine cylinder misfires (i.e. the fuel within a cylinder has not been exploded and is discharged into the atmosphere). After this detection, a warning is given to the driver to repair his or her vehicle. This requirement will become law in California (and other states) in 1996. Therefore, some solution must be found. Hardware solutions have been proven to work but with cost and reliability problems. Algorithm solutions that use existing sensor data and processors are the current research area because of the low cost and reliability improvements.

Work in the area has proceeded slowly and can be summarized in [11] and [12]. Techniques described in these papers rely on physical approaches that are not necessarily optimal (frequency analysis and acceleration changes, respectively). The data for this application comes from a flywheel speed sensor. In essence, the sensor measures the time it takes the flywheel to rotate between two of its edges. Obviously, this is an inversely proportional measure of RPM. If an engine cylinder misfires, the flywheel loses some of its momentum. The time between the edges increase (i.e. RPM decreases) and a misfire should easily be detected. This, of course, is not true since there are so many variables in an engine and its associated output (i.e. flywheel speed). Figure 6 depicts a signal with misfires shown. Note the small difference between the misfire values and those without misfires (acceleration is defined as the difference between RPM samples).

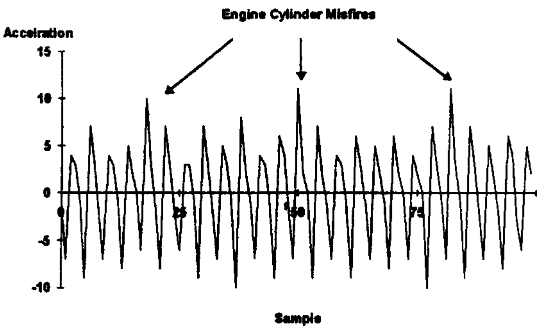

Figure 6: Speed Variation Waveforms

In figure 7, creative use of signal processing techniques have separated the "signals" (i.e. engine misfires) from the "noise." These techniques were matched to the physics of the problem as in the vehicle crash detection problem described in section 4. Work is still continuing on this problem.

5. CONCLUSIONS

Automotive signal processing applications are far different from their counterparts in communication, aerospace and consumer products. These differences require a mix of math and physics in an artistic fashion. In this paper, we have shown two examples where this has been possible.

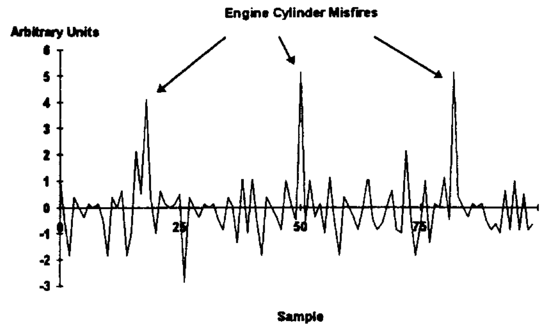

Figure 7: Artistically created measure to separate misfires from nominal engine events

REFERENCES

[1] Gardner, W. A. "Author's Comment in SP Forum," Signal Processing Magazine, April 1994, pg. 14-23

[2] Gioutsos, T., "Testing Techniques for Electronic Single Point Sensing Systems," SAE International Congress and Exposition, Paper # 940803, 1994

[3] Behr, L., " A Magnetically Damped Crash Sensor Providing Testability and Dynamic System Reconfiguration," SAE International Congress and Exposition, Paper # 910277, 1991

[4] Breed, D., et al. ,"Performance of a Crush Sensor For Use With Automobile Air Bag Systems," SAE International Congress and Expo., Paper # 920122, 1992

[5] Gioutsos, T. and Gillis, Ed " Tradeoffs and Testing for Frontal Crash Sensing Systems," SAE Worldwide Pass. Car Conf. and Expo., Paper # 932911,1993

[6] Diller, R., "Electronic Sensing of Automobile Crashes for Airbag Deployment," SAE International Congress and Exposition, Paper # 910276, 1991

[7] Bergfried, D., "Airbag Control Modules - Perf. and Reliability," Convergence 92, Paper # 92C054, 1992

[8] White, C and Behr, L., "Inflatable Restraints Sensing and Diagnostic Strategy," SAE International Congress and Exposition, Paper # 901120, 1990

[9] Gioutsos, T., "A Predictive Based Algorithm for Actuation of an Airbag," SAE International Congress and Exposition, Paper # 920479, 1992

[10] Gioutsos, T. and Piskie, M., "Automobile Crash Modeling and the Monte Carlo Method," SAE International Cong. and Expo., Paper # 920480, 1992

[11] Ribbens, W. B. and Park, J. , "Road Tests of a Misfire Detection System," SAE International Congress and Exposition, Paper # 940975, 1994

[12] Klenk, M., et. al., "Misfire Detection by Evaluating Crankshaft Speed - A Means to Comply with OBD II," SAE International Congress and Exposition, Paper # 930399, 1993