

The Autonomous Recognition of Left Behind Passengers in Parked Vehicles

2011-01-0582

Published
04/12/2011

Christian Fischer
University of Wuppertal

Thomas Fischer
Delphi Delco Electronics Europe GmbH

Bernd Tibken
University of Wuppertal

Copyright © 2011 SAE International

doi:10.4271/2011-01-0582

ABSTRACT

The unattended left behind of children in parked vehicles is one of the major causes of lethal or serious injuries to children in non-traffic accidents in the U. S. For this reason Delphi is interested in the development of a low cost left behind occupant recognition so that its safety division launched the evaluation of different approaches for a reliable detection system in 2008. This contribution discusses the sensor evaluation, experiments under different conditions and the classification via data mining algorithms based on two potential approaches. The first one uses high sensitive analogue accelerometers at the car chassis and the second one is based on a pressure mat in the seat. Occupants inside the vehicle produce vibrations at the car chassis which can be monitored by the accelerometers. The needed electronic and different experimental results are explained in regard to an autonomous left behind recognition. Subsequently the experiments with the pressure mat are discussed. This system is appropriated for the determination of the physiological parameters of the seated occupant and is based on a reengineered series product - PODS-B. Its signal processing and the extracted signals are described and the relevance for the following classification paragraph becomes emphasized. Finally the gained information of the evaluated sensing elements is used to rate four different classification methods (k-NN, SVM, J48, PNN). The results are discussed and the proper classifiers are highlighted. Out of this the further development steps are defined and the benefit of the applications is characterized.

INTRODUCTION

Several researches [1,2,3] determined that hyperthermia (heat stroke) is an underestimated risk which can lead to serious injuries or even to death. In the U. S., between 1998 and 2009, 444 left behind children in cars died due to hyperthermia [3]. The National Highway Traffic Safety Administration (NHTSA) initiated a research [1] which shows that hyperthermia is the second leading cause of death for children in non-traffic fatalities in the U. S. (19.6 %); the first one is backover (49.5 %). Most of these tragedies could be prevented by not leaving children unattended in motor vehicles and 14 states in the U. S. already reacted with a law that prohibits the unattended left behind of children in cars [4, 5]. Most of the car owners/drivers do underestimate how fast and high the temperature inside a vehicle can increase on a normal summer day.

A research by Jan Null (San Francisco State University) [3] illustrates the situation and shows how fast a standard vehicle's interior can heat up (Fig. 1,2,3). This simulation describes a parked vehicle at a parking lot on a common summer day. At the beginning an ambient temperature of 80 °F is given (Fig. 1). One hour later the passenger compartment is heated up to 123 °F (Fig. 2). Figure 3 summarizes the trend of the average difference between the vehicle's interior and the ambient temperature.

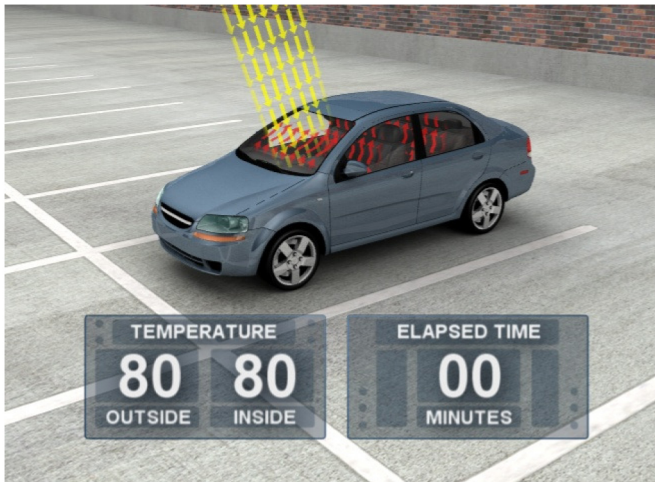


Figure 1. Car temperature at the beginning [3].

The first critical point is reached 10 minutes after the launch of the experiment-based simulation [3]. With an ambient temperature of 80 °F it would lead to a temperature inside the vehicle of 100 °F which is the beginning of fever for human beings. If there is no possibility to open windows, drink or activate the air condition, every minute inside the car becomes more and more uncomfortable. After 20 minutes the interior temperature reaches the critical body temperature of 109 °F which leads to death if the dwell time is too long. The raise of the vehicle's interior temperature is a non-linear function over time and depends on several conditions like car body and interior color or the kind of glass that is used for the windows (e. g. tinted). One of the biggest factors is the color of the passenger compartment's interior [3]. Children are the most endangered occupants, because their bodies abet a fast heat up.

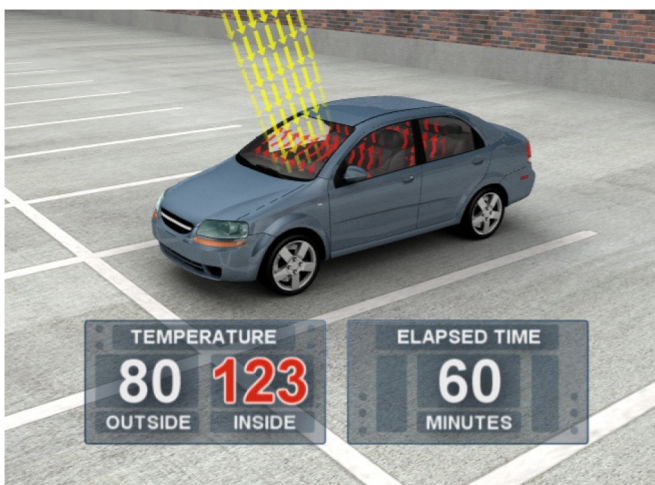


Figure 2. Car temperature after one hour [3].

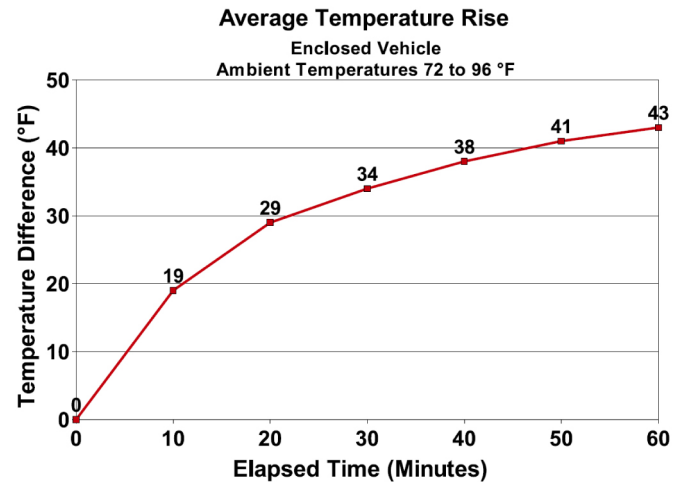


Figure 3. Rising temperature inside the vehicle's passenger compartment [3].

The first reason is that the childish body is still learning to control its core temperature and the second reason is based on a physiological condition called surface-area-to-volume ratio (SA:V). The

$$SA : V = \frac{\text{SurfaceArea} \left[\frac{m^2}{m^3} \right]}{\text{Volume}} \quad (1)$$

of an object describes the ratio of its body surface area to its volume. It lowers with the raise of the volume of an object. The surface of a human being is correlated to its absorbed heat or cold, therefore objects with more volume (adults) need a longer time to be heated up than objects with less volume (children) under the same conditions. Out of it the risk of serious injuries due to external heat influences is even higher for children. Unattended children and older grown-ups are not able to help themselves out of this health threatening situation; a left behind detection would be able to call assistance. Initiated by the described circumstances and requests by customers Delphi's safety division started the development of a left behind occupant recognition in 2008.

The presented approach describes the use of accelerometers directly mounted at the car chassis to fulfill the task of a left behind occupant detection. An additional sensing element is evaluated in regard to improve the detection reliability of the target system. At the beginning a short explanation of the used test car and its vibration characteristics in the observed frequency domain is given. Afterwards the tremor of human beings as vibration source is characterized. Based on this, the accelerometer assembly and its signal processing are explained. Also the compensation of external disturbances by passing heavy traffic is exemplarily shown. The second sensing element is based on a series produced silicon oil filled bladder mat (PODS-B) which normally measures the applied loading force on the equipped seat. A modified use of

the bladder, its signal processing path and the extracted physiological signals become characterized. For the extraction of a pulse equivalent value the Hilbert transform is shortly explained and applied to the monitored pressure information. The given laboratory assemblies are tested under different conditions (e. g. changing tire pressure, running engine) and the monitored data is analyzed in regard to an autonomous recognition via data mining algorithms. This is the basis for the following classification paragraph. First the compared algorithms (k-NN, SVM, J48 and PNN) and their characteristics are specified. The use of the feature extraction to compress the sensor information leads to a correlation-based ranking (CFS) of the feature space. Finally the results of four classifiers (k-NN, SVM, J48 and PNN) on three different sensing combinations are compared and further development areas are defined.

INVESTIGATED SENSING APPROACHES

ACCELEROMETERS AT THE CAR CHASSIS

In prior experiments [6, 7] it was discovered that information about the occupancy status of a vehicle can be extracted from its chassis vibrations measured with accelerometers. Figure 4 displays schematically the main components and their locations at the test car. The chosen locations of the three accelerometers have different positions in reference to the center of mass of the car which is nearby the position of the data acquisition (marked in Fig. 4). It is the pivot point of the vibrating system.

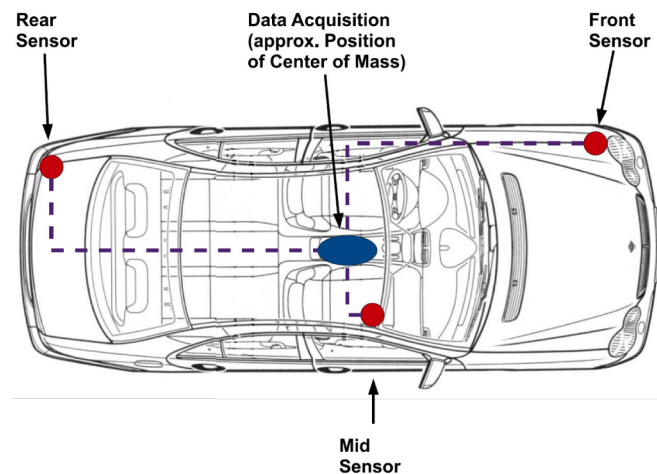


Figure 4. Accelerometer locations at the test vehicle [8].

In a strict abstraction every vehicle can be represented by mass-spring-damper systems to gain information of the possible natural frequencies of the observed system [9, 10]. Figure 5 shows the schematic of one tire and its suspension in a mass-spring-damper abstraction. The spring constant of the

tire and its mass (C_1, m_1) build the basis for the suspension (C_2, k_2) and the proportionate mass of a quarter of the car chassis (m_2). On top is the passengers mass (m_3) seated on the passenger seat represented by its spring and damper constants (C_3, k_3). Many investigations into the occurring natural frequencies and their effects on the passengers were done by car manufacturers.

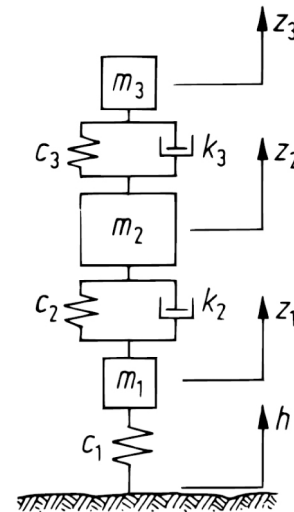


Figure 5. Mass-spring-damper abstraction of a quarter of a car [11].

The main frequencies up to 15 Hz are summarized in figure 6. The natural frequency of human beings also represents the frequency range of the highest sensitivity to external vibrations of a person [11]. A seat's transfer function has an attenuating character above 5 Hz. The frequency characteristics of the mentioned system support the propagation of the vibration produced by an occupant.

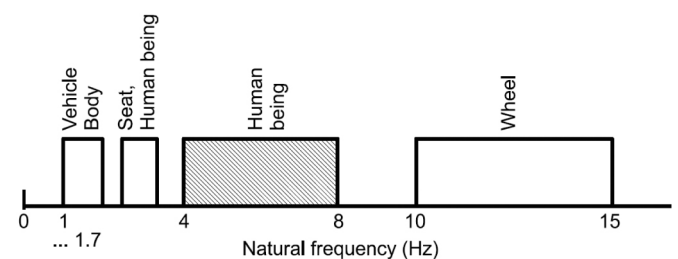


Figure 6. Occurring natural frequencies of a car up to 15 Hz [11].

Preliminary tests with a setup car resulted in a measurable signal produced by a person seated in the parked car. This is based on a phenomenon which is medically known as human tremor. It is an unintentional, rhythmic, oscillating muscle movement which cannot be suppressed by the individual itself [12]. This and the fact that it is provided by every

healthy person makes it interesting for the development of a left behind occupant detection.

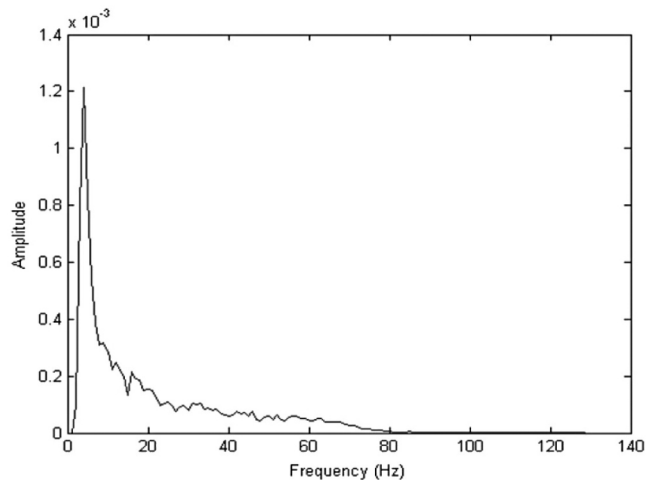


Figure 7. Frequency spectrum of a human tremor directly measured at the body of a test person [13].

Figure 7 displays the frequency spectrum produced by a healthy human tremor which is taken directly at the body of a test person [13]. The most important information in figure 7 is that the tremor produces a peak at approximately 4 Hz. A healthy human being has got a signal frequency between 4 and 12 Hz [12]. Medically the normal human tremor frequency spectrum is classified as mid- or high-frequency tremor (Table 1) and considers frequencies between 4 and 15 Hz.

Table 1. Medical classification of human tremor frequencies [12, 14].

Medical Category	Frequency Range
Low-frequency tremor	Below 4 Hz
Mid-frequency tremor	4 up to 7 Hz
High-frequency tremor	7 up to 15 Hz

This limits the observed range of our classification approach up to 15 Hz. Founded on this information different experimental setup vehicles were built up. The mentioned system consists basically of three high sensitive analogue accelerometers directly mounted to the car chassis which are located at the front, mid and rear of the car (Fig. 3). They convert the vibration signals of the car chassis into analogue voltages with a resolution of 1,200 mV/g ($g = 9.81 \text{ m/s}^2$). Before they are simultaneously digitized by a 16-Bit Analogue-to-Digital Converter (ADC) the signals become amplified and band-pass filtered (pass-band approx. 1...50 Hz). With a sample rate of 1,024 samples per second over a sampling period of 10 seconds the ADC provides a time discrete vector per sensor for the further processing of the signals. Digital filters preprocess the gained time-domain

signals to prepare the extraction of the occupancy information of the observed vehicle.

ACCELERATION MEASUREMENTS AT THE CAR CHASSIS

Based on this assembly, different scenarios for occupancy and parking conditions were defined and tested (e. g. parking situations, tire pressure, vehicle loading). The tests confirmed the prior theoretical considerations about the vehicle's vibration behavior and pointed the actual system boundaries out. Most interesting were the tests with different occupants in the vehicle. A decrease of the signal magnitude in correlation with the decline of the muscle mass of the test person (Adult $\rightarrow$ Child $\rightarrow$ Baby) was observed. In case of a motionless sleeping infant seated in its child seat a temporary signal loss was monitored (approx. 10 % of all sleeping baby measurements). A partial signal loss can be compensated by longer measuring periods or a confidence filter at the end of the classification decision to get a more stable and reliable system answer.

Another critical situation for a vibration-based occupant detection is while external disturbances interfere. In the case of the requested application this is given by passing heavy traffic directly nearby the parked car. This led to a misinterpretation of the spectra in the frequency domain (cp. Fig. 8).

To determine the disturbances by passing heavy traffic several signal transforms are used, like the Wavelet Transform (WT) or the Short-Term Fourier Transform (STFT). In figure 10 the tremor produced frequency is constant over time, instead of this the disturbances produced by passing heavy traffic (Fig. 9) show peaks sharp in time.

Based on the given experimental setup and the gained results of several tests the use of a second input by another sensor was studied. This approach presents a potential second sensor for the requested occupant classification task by using a silicon filled bladder mat.

PRESSURE SENSING IN THE SEAT

The second sensing unit is based on the Passive Occupant Detection System (PODS-B, Fig. 11). This system is designed to classify the occupant seated in the front passenger seat for potential airbag suppression [15]. It normally consists of a pressure sensor, bladder assembly, seat belt tension sensor and an Electronic Control Unit (ECU). The sensing system detects the loading force on the equipped seat and classifies the seat as empty or the occupant as an adult or infant/child. This information is used to disable parts of the airbag in case of a detected child seated in the front passenger seat to reduce the potential for inflation-induced injuries or fatalities to children. PODS-B is developed to

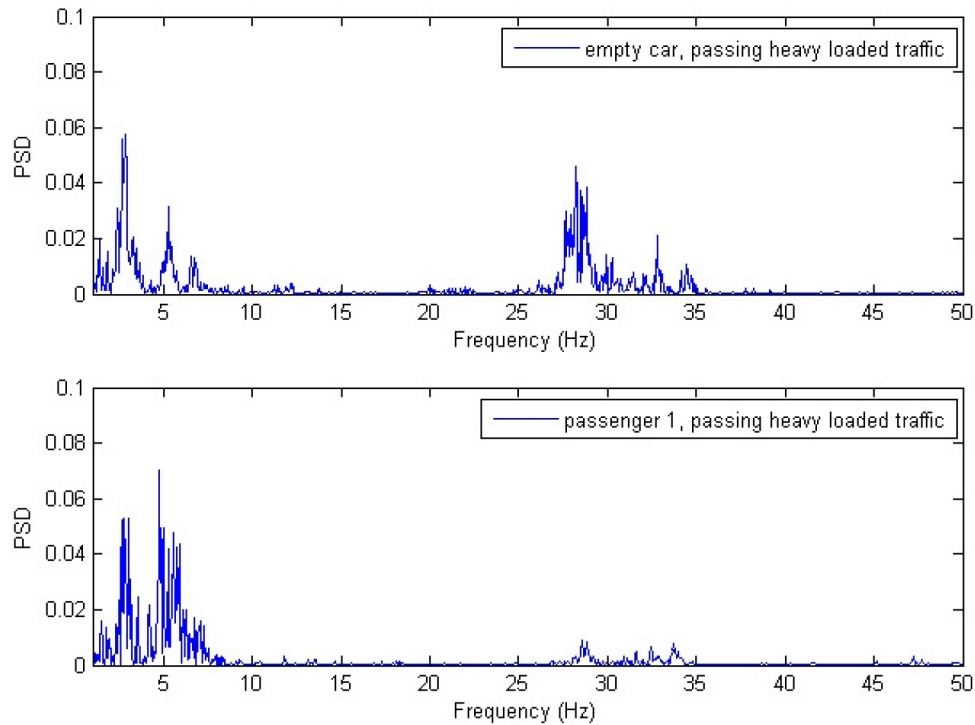


Figure 8. Spectra at a very busy road (top: Empty Car, bottom: Occupied Car) [7].

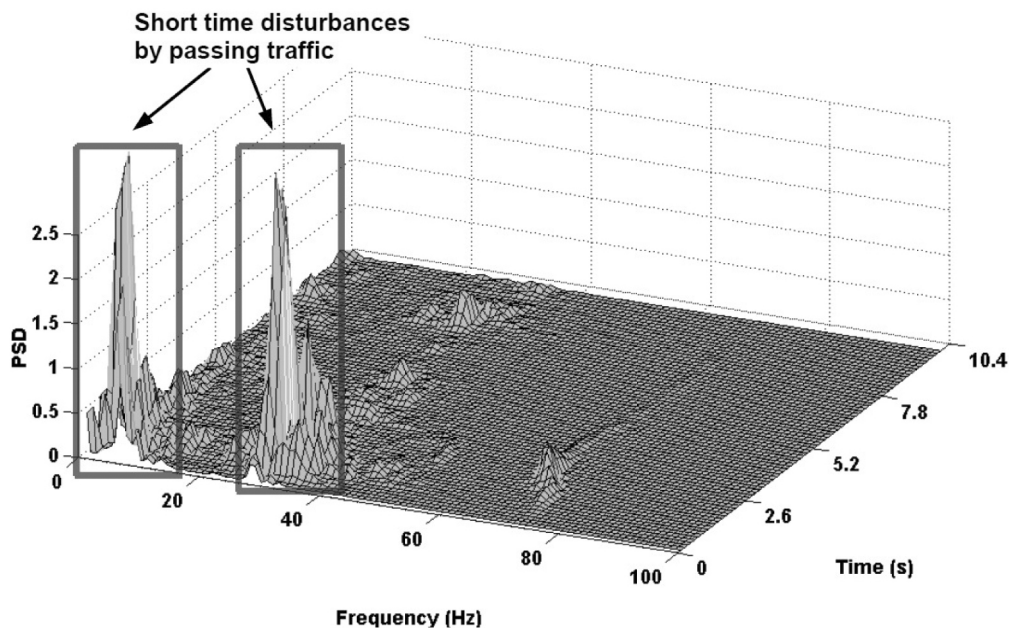


Figure 9. Accelerometer signal of the empty vehicle in STFT domain (see Fig. 8) [8].

fulfill the requirements of the advanced airbag regulation defined by the FMVSS 208 (Federal Motor Vehicle Safety Standard for Occupant Crash Protection) [15] and it is a series product since 2001. In this operation mode only the DC information of the pressure signal is processed by the ECU.

Nevertheless also the AC signal provides further information about the occupant on the seat that can be used to extract heartbeat and respiration movement as shown in [16]. For the use in the mentioned application the seat belt tension sensor and the ECU are not needed. Instead of the ECU a special data acquisition unit, which was specially designed for the extraction of the physiological parameters, is used. It consists