UNATTENDED CHILDREN IN CARS – RADIOFREQUENCY-BASED DETECTION TO REDUCE HEAT STROKE FATALITIES

Thierry Mousel
**Peter Larsen**
Holger Lorenz
IEE S.A.
Luxembourg

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ABSTRACT

A sad type of incident, which predominantly happens in warm and sunny seasons, is children dying of hyperthermia inside vehicles. In the US, there are, on average, 37 heat-related fatalities per year. In about 70% of these cases, the child was either forgotten or intentionally left inside the vehicle. Temperatures rise very quickly in a car that is parked in the sun, and can reach a critical level within less than 20 minutes. Although the overall number of hyperthermia fatalities can seem relatively low compared to the overall road fatalities, the incidents are dramatic, as the victims are predominantly very young and defenseless. A sensor, integrated behind the headliner of the vehicle, uses radiofrequency (RF) signals to detect the vital signs of a child. The sensing unit emits signals in the 24 GHz ISM band and evaluates the reflected signal. The system is sensitive enough to detect the small breathing movements of a sleeping baby, and is even capable of detecting the child under difficult circumstances, such as through the sunshade of a rearward-facing child seat. Once the presence of a living being is detected, various alerts or countermeasures can be initiated. A vehicle-based sensing approach is the most promising, as it can potentially use all of the vehicle's available infrastructure to initiate warnings or countermeasures. Further studies on warning strategies may be needed to identify the most effective and acceptable ones.

INTRODUCTION

In 2016 there were 39 heat-related fatalities inside a vehicle in the US, 15 more than in 2015. At least 702 children have died from heat stroke in a vehicle since 1998 [1].
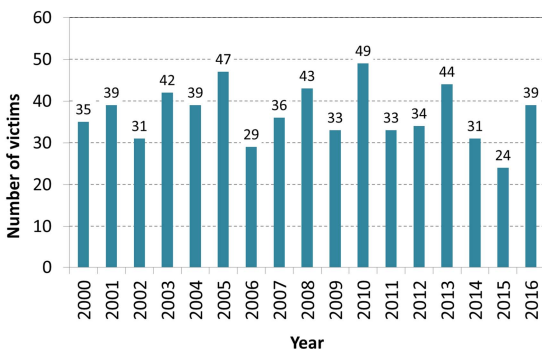
Figure 1. In-vehicle heat stroke fatalities in the US

In about 70% of these cases, the child was either forgotten or intentionally left inside the vehicle. In the remaining cases, the child managed to get into an unlocked vehicle but was unable to exit again.

Although it seems unthinkable to forget a child in a car, a review of the incidents shows that distraction, a change in the daily routine, or misunderstandings play a major role. Therefore, it can potentially happen to anybody irrespective of educational background, etc. When children were intentionally left in the car, the caretaker either ignored the risk of leaving the child inside, or it simply took them longer to get back to the vehicle than initially planned. Temperatures rise very quickly in a car that is parked in the sun, and can reach a critical level in less than 20 minutes. These types of hyperthermia incidents also take place in Europe and other parts of the world, but due to the lack of databases covering them, the full scope of the problem is unknown.

Although the overall number of hyperthermia fatalities can seem relatively low compared to the overall road fatalities, it could be worth looking back and making a comparison to the airbag-related fatalities seen in the US in the late 1990s and early 2000s (see Figure 2). About 120 children died due to deploying airbags and, as a consequence, the advanced airbag rule was introduced into FMVSS 208. The changes to

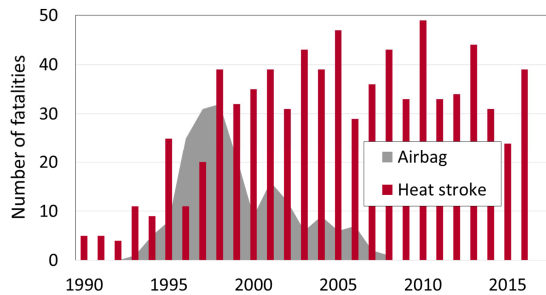FMVSS 208 have successfully contributed to the reduction of those kinds of incidents.

Figure 2. Heat stroke versus airbag fatalities

Attention should also be given to the fact that the social consequences of heat stroke fatalities are often dramatic. The victims are very young and defenseless, the caretaker is often a parent or direct relative, and society seems to have little understanding about the memory failures that lead to the dramatic consequences.

CHILDREN ARE ESPECIALLY VULNERABLE TO HEAT STROKE

Heat stroke occurs when the body temperature reaches or exceeds 40 degrees Celsius (104 degrees Fahrenheit) from an external or environmental exposure to heat. To place this in perspective, in 27 degrees Celsius (80 degree Fahrenheit) weather, the inside temperature of a car can increase to 55 °C (130 °F) in less than one hour. Children are especially vulnerable to heat stroke because of their body size and relative inability to release heat compared to adults.
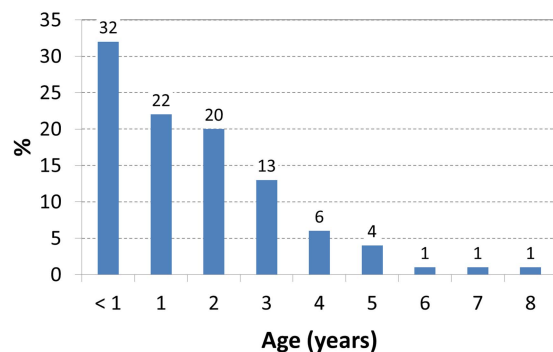

Figure 3. Share of heat stroke victims by age group

A child's body temperature can increase at a rate of 3 to 5 times faster than for an adult. The rapid rise and consistently high temperatures in the vehicle's interior do not allow a child to release body heat through normal methods. In the most severe heat stroke form, there is an increased oxygen demand, which is coupled with heat-related death to cells in many organs of the body, particularly in the brain. These effects can finally lead to death, but even if a child were to survive heat stroke from being left in the vehicle, it may suffer permanent neurologic damage.

HOW TO DETECT A CHILD LEFT IN A VEHICLE

Today's Vehicles Have Many Reminders
There are plenty of "comfort" reminders that have been added to modern vehicles. The driver is informed if he has left the lights on, forgotten the key in the ignition, or when the windshield washer liquid level is low. In the safety-related area, many vehicles nowadays are equipped with seat belt reminders alerting the occupants that they have forgotten to buckle up. But if a child is left unattended, no vehicle can detect this and warn you about it. So, when thinking about ways to tackle heat stroke fatalities, the resulting questions are: a) how to detect that there is an unattended child in the car; b) what is the appropriate warning or countermeasure strategy.

In recent years some technical concepts have started to emerge to address the problem of at-risk unattended children. Back in 2012, the US National Highway Traffic and Safety Administration (NHTSA) evaluated a few aftermarket systems, and found them to be unreliable or difficult to install [2]. In a subsequent technical report published in 2015, NHTSA proposed a test methodology for a functional assessment of "Unattended Child Reminder Systems" and expressed the hope it might help innovators bring more robust child safety products to market [3].

For the 2017 GMC Acadia, General Motors has introduced an alert system that, once the car is turned off, reminds the driver to check the rear seat whenever a rear door was opened prior to or during the trip. So a simple door switch monitoring has been implemented and has been linked to the "child reminder alert". Evenflo sells a child seat which, in combination with an ODB-port connected electronic, chimes an alert if the child seat buckle is closed and the engine is turned off. What both systems have in common is that they use indirect information to determine the possible presence of a child.

Radiofrequency-Based Detection

In the past IEE has investigated various technologies for their suitability to detect unattended children, independent of whether they are installed in a child seat or not. Among the evaluated systems were seat-based sensors, thermal sensors, or optical systems. But each of them had certain weaknesses that would not have allowed detection of a child in certain normal circumstances.

Passive 2D camera-based systems are able to classify human contours by looking top-down, but will not work when the field of view is blocked – for example if the child restraint system is covered by a sunscreen or other material - or when it is dark. Infrared cameras would be able to detect children's body heat at night too, but human bodies may not be properly detected when the car interior is already hot (e.g. during the summer). Piezoelectric foils are very sensitive to heartbeats, but also to vibration. This makes it impossible to detect children when the car is parked next to a road with heavy traffic. In addition, integrating piezoelectric sensors in the seat is difficult.

Radiofrequency-based detection has allowed IEE to overcome those hurdles. A sensor, integrated behind the headliner of the vehicle, uses radiofrequency (RF) signals to detect the presence of a child on the rear seat after the ignition has been switched off. The sensing unit emits RF-signals that cover the rear bench, and it evaluates the reflected signal. A specific algorithm filters the signals and allows detection of the vital signs of a human being.

VITASENSE

The Sensing System

IEE's VitaSense emits signals in the 24GHz ISM band, with a very low transmission power of 4mW, leading to a specific energy absorption rate more than 20 times below that of a cell phone.

The system is sensitive enough to detect the small breathing movements of a sleeping baby, and is even capable of detecting the child under difficult circumstances, such as through the sunshade of a rearward-facing child seat. As the sensor is vehicle-based, the child is detected without the need for a specific child seat.
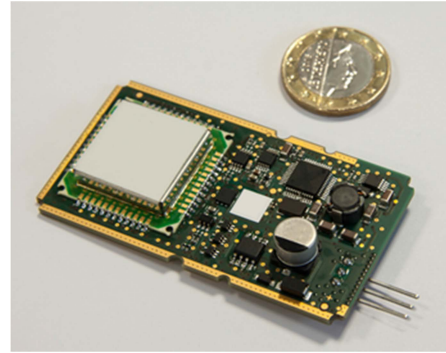

Figure 4. VitaSense ECU

Measurement Principle

The continuous wave radar measures the breathing motion of the child's abdomen while sleeping, or overall body movements when it is awake.

Because electromagnetic waves are used, the sensor is able to make a robust decision independently of air currents and the temperature inside the cabin. The electromagnetic waves can penetrate through sunshades and clothing, and thus work independently from light conditions. Human breathing motions can clearly be distinguished from background noise. As the sensor can be completely covered by plastic or cloth trim, it is easy for car manufacturers to integrate. This also makes it easy to connect to, and make use of, the vehicle infrastructure.

As the sensor is mounted in the ceiling behind the headliner, children in forward-facing and rear-facing child restraint seats, or on boosters can be detected. Figure 5 shows the position related to the seat and the sensor itself.
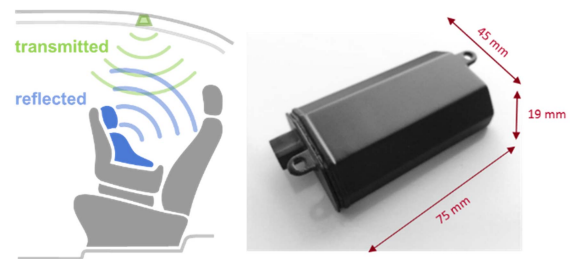

*Figure 5. RF-module integrated behind the vehicle headliner*

The classification method

The reflected signals are processed so that the level of motion observed can be evaluated. This is done by evaluating the receiver's I and Q signals, which in the complex space describe a circle for a

single point motion. The radius of the circle is proportional to the level of motion in the field of view. Since only background noise is present if there is no motion observed, detection is possible within 1 to 2 seconds, if a significant level of motion is observed. This classification method is called "Global Motion Recognition".

The radar cross section of a very small sleeping new-born is so small that the level of motion is lower than the threshold selected for the "Global Motion Recognition". In order to detect a sleeping new-born, the reflected signals are analyzed for the presence of a periodic motion (breathing). A robust decision is thus possible after 8-10 seconds, if the reflected signals are so low that they could be background noise. This classification method, discriminating small breathing patterns from background noise, is called "Sleeping Child Recognition".

Figure 6 illustrates the overlap of the power level of the background noise and the breathing motion of a sleeping new-born.
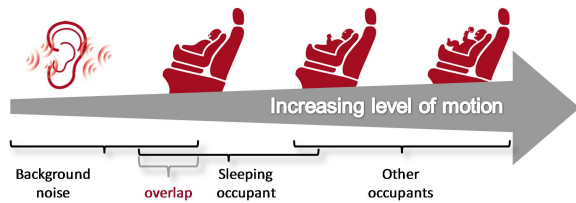

Figure 6. Time to classification depends on level of motion

Detection Versus Non-Detection
It is important to design an alarm system so that it properly detects the object to be detected, in this case forgotten children. However, it is also important to design a system so that false alarms are avoided wherever possible.

Figure 7 shows an example of a one-month old baby in a child seat with a closed sunscreen. The left-hand side shows the pre-processed received radar signal, and the right-hand side shows the sleeping child recognition algorithm processing result, which shows a periodic signal that meets the algorithm's settings for the regularity and periodicity of the signal.
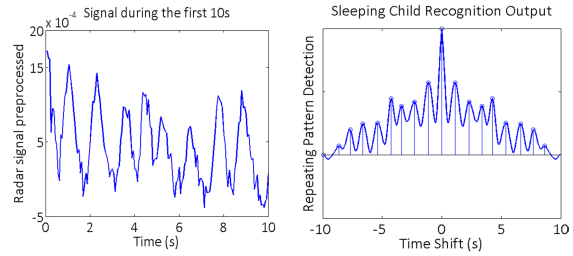
Figure 7. Sleeping Child Recognition for one-month old child

Figure 8 shows an example of rain falling on an empty car, thus increasing the noise level, giving an observed motion level similar to that of the sleeping one-month old baby shown in Figure 7. The right-hand side again shows the sleeping child recognition algorithm processing result, which now shows no periodicity in the signal, so the situation is classified as background noise and a false alarm is avoided.
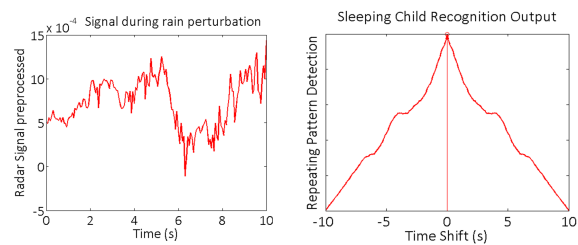

Figure 8. Rain on empty car

A Dedicated Test Tool
As the aim of the system is to detect real humans, it would be ideal to have suitable test candidates available at any time. Human babies played a major role in the development of the system and the fine-tuning of the algorithm, however they are not always available. Therefore, IEE has developed a dedicated test tool to reproduce the breathing pattern of a sleeping baby.

Figure 9. Dummy reproducing breathing patterns

A baby doll has been fitted with a pneumatic bladder in the abdomen. The breathing pattern and amplitude reproduced by the bladder has been aligned with the weakest parameters that were identified in a real human baby. So it has been designed to represent a "worst case" sleeping newborn. This dedicated test tool allows tests to be run whenever needed. The tool is also used for VitaSense system demonstrations.
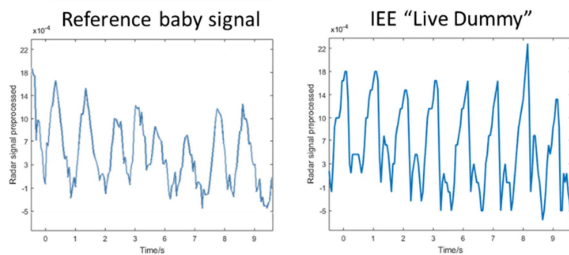
Figure 10. Breathing pattern - human baby versus test tool

Whenever possible, additional data based on real babies is recorded to create a broader database of breathing patterns. Once the data is recorded it is used for continued development and fine-tuning of the algorithms.

VEHICLE TASK – WARNINGS AND COUNTERMEASURES

When the presence of a living being is detected, various alerts or countermeasures can be initiated, depending on the capabilities of the vehicle, for instance: the vehicle horn or a distinct sound, a text message to a mobile phone, using connectivity features to alert third parties (connected car apps, emergency services, etc.), activation of the air-conditioning.

Figure 11. Variety of warnings and countermeasures

Based on detection tests with babies under various conditions, the RF-based detection method has been thoroughly tested and found to be robust. Still, for a sleeping baby the detection is not necessarily immediate: It can take up to 30 seconds. Hence, a local warning may not be sufficient, and ideally some warning measures should reach beyond the immediate vicinity of the vehicle. Further studies on warning strategies may be needed to identify the most effective and acceptable ones. It is also important to clarify that the system is a reminder providing an additional safeguard, but does not ensure the prevention of heat stroke fatalities per se.

CONCLUSION

On average, 37 children die of hyperthermia inside vehicles every year in the U.S. This can seem relatively low compared to the overall road fatalities, but the incidents are dramatic as the victims are predominantly very young and defenseless.

A sensor, integrated behind the headliner of the vehicle, uses radiofrequency (RF) signals to detect the vital signs of a child, and is sensitive enough to detect the small breathing movements of a sleeping baby, even under difficult circumstances, such as through the sunshade of a rearward-facing child seat.

A vehicle-based sensing approach is the most promising, as it can potentially use all of the vehicle's available infrastructure to initiate warnings or countermeasures. Further studies on warning strategies may be needed to identify the most effective and acceptable ones.

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[2] Arbogast K., Belwadi A., Allison M., "Reducing the Potential for Heat Stroke to Children in Parked Motor Vehicles: Evaluation of Reminder Technology", NHTSA (DOT HS 811 632), July 2012.

[3] NHTSA (DOT HS 812 187), "Functional Assessment of Unattended Child Reminder Systems", July 2015.