RF-based Child Occupation Detection in the Vehicle Interior

Andreas R. Diewald[1,2], Jochen Landwehr[1], Dimitri Tatarinov[1], Patrick Di Mario Cola[1], Claude Watgen[1]
Catalin Mica[1], Mathieu Lu-Dac[1], Peter Larsen[1], Oscar Gomez[1], Thierry Goniva[1]
1. IEE S.A.; 11, rue Edmond Reuter; L-5326 CONTERN; Luxembourg; Thierry.Goniva@iee.lu
2. Hochschule Trier; Schneidershof; D-54293 TRIER; Germany

***Abstract*—The authors report about a commercial development of a radar-based presence detection for automotive interior applications. The major focus is the detection of forgotten children on the rear bench of a vehicle in order to save them from hyperthermia. The occupancy decision criteria is primarily derived by a measured quantity called R-value. Critical occupancy states are verified by a correlation-based approach, fulfilling automotive safety requirements, which allows the detection of newborns. Thus, the sensor can also be used for other applications, e.g. rear bench seat belt reminder functionality. Due to the Doppler-based approach the sensor can further be applied for vital sign monitoring of breathing and heart beat for autonomous driving applications.**

***Index Terms*—automotive radar, presence, occupation detection, Doppler radar.**

I. Introduction

In the 90's children were often killed by overpowered airbags when seated in the front of the passenger compartment in the event of a car accident. This serious issue was at least solved in part by advanced airbag systems igniting in several steps depending on the occupant class. Furthermore, awareness campaigns were initiated in the U.S. to convince caretakers to place children in the back or even prohibit people to transport their children on the front seats.

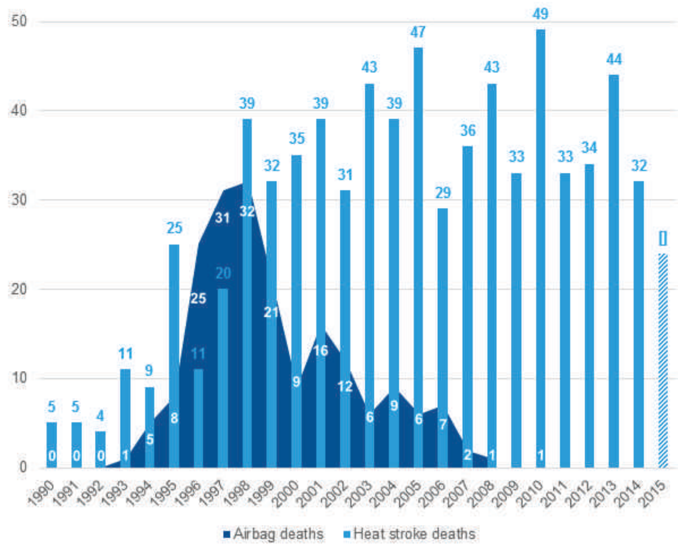

Fig. 1. Child vehicular heat stroke[1] vs. front seat passenger deaths[2]

The statistics in fig. 1 shows the number of children deaths per year (in the US only) and highlights the decrease of airbag deaths in the end of the nineties. As an outcome of these campaigns people started to forget their children, after they learned to have the children in the rear. Thus, the number of children dying by heat stroke started to increase and exceeded the number of airbag deaths mid of the nineties.

The reason for forgetting children is that parents become distracted by the daily routine or when the children are out of the sight (e.g. on the rear bench). Children can be unknowingly left behind in the rear seat by even the most responsible parents and caregivers. It is not a phenomena of a socially weak population. This trend is not specific for the US where statistic data is readily available. Media reports around the world that heat stroke deaths is a global issue.

In the following, the authors present a electromagnetic sensing system called VitaSense to detect occupants on the rear bench independent from a child restraint system.

II. Comparison of Sensor Systems

The luxembourgish company IEE is an automotive supplier of occupant detection systems. Their main product is a foil-based system, which is integrated in the seating area of vehicles and which measures by pressure (tactile sensors) or by capacitive coupling to the car body. Neither sensor type is able to detect children wether are present in a restraint systems. Furthermore children in restraint systems should not activate the airbag system with the above mentioned systems in the event of an accident. Thus, these systems are well established for seat belt reminder or occupant classification systems, but not suitable for child presence detection.

The detection of very small and slepping newborns in a child restraint seat needs a more advanced technology. Passive 2D Camera-based system are able to classify for human contours by looking top-down, but are failing fast when the child restraint system are covered by cloth (e.g. sunscreen) or when it is dark. Due to the body heat, infrared cameras are able to detect children by night, too, but human bodies could not be detected when the car interior is already heated up (e.g. in summer time).

Piezoelectric foils are very sensitive to heart beat, but also to vibration. This makes it impossible to detect children when the car is parked beside a heavy traffic road. Breathing measurements with piezoelectric sensors integrated in the seating area is difficult, as tests in the IEE R&D department have shown.

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Continuous wave radar systems (CW-radars) are able to detect breathing and heart beats of humans due to the breathing motion or the seismocardiographic motion of the skin. CW-radars are robust in decision making independently of air currents inside the cabin and independently of interior temperature. The electromagnetic waves can penetrate through sun shades and clothing, and due to the active - but invisible - illumination the sensor works independently from light conditions. Human breathing motions can clearly be distinguished from background noise. Thus, a radar-based system would be the optimal technology for detection of forgotten children. In addition, the sensor can completely be covered by plastic or cloth trim which allows vehicle-based integration by the car manufacturer and use of the vehicle infrastructure (LIN/CAN bus, alarms, emergency call, etc.).
As a result of this comparison a CW radar-based motion detector has been developed in the 24 GHz ISM band. The sensor detects occupants based on movements or breathing, even when they are sleeping. The sensor is mounted in the ceiling behind the headliner which allows the surveillance of forward-facing and rear-facing child restraint seats or on boosters. Fig. 2 shows the position related to the seat and the sensor itself.

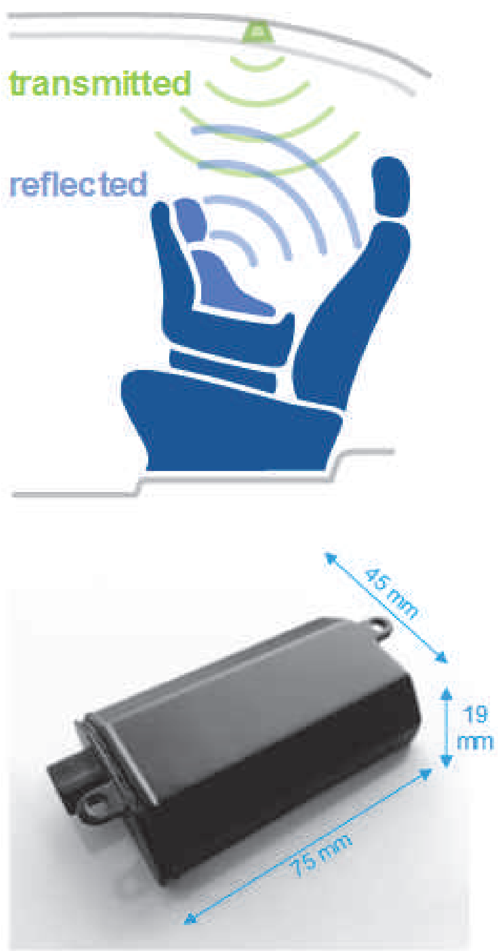

Fig. 2. Sensor location in the passenger compartement and sensor system

III. Radar Sensor System

The sensor is a classical CW-radar system with an optimized antenna characteristic in order illuminate the whole rear bench. The RF-front-end mix down into the base band where the analog data is digitized and processed for classification.
A normal classification is done within 1 to 2 seconds by using the R-value, which is a measure for the received power out of the scene from moving targets. In the complex domain the I/Q signal describes a circle for a single moving target [3].

$$y_I(f_o, t) = A \cdot \cos\left(2\pi \cdot f_0 \cdot 2R(t)/c0\right) \tag{1}$$

$$y_Q(f_o, t) = A \cdot \sin\left(2\pi \cdot f_0 \cdot 2R(t)/c0\right) \tag{2}$$

The amplitude A is the radius of the circle which can be estimated by different methods like variance calculation or a circle fit method. This classification is called ”Global Motion Recognition”[4]. If there is no motion, only the background noise would be measured. The power of the noise is non-zero which results in a non-zero R-value. Due to a noise-oriented threshold in the R-value classification, the sensor would not alert.
The radar cross section of a very small newborn is not sufficient in order to exceed the noise threshold in the R-value classificator. Fig. 3 shows schematically the overlap between the power level of background noise and of a sleeping newborn.

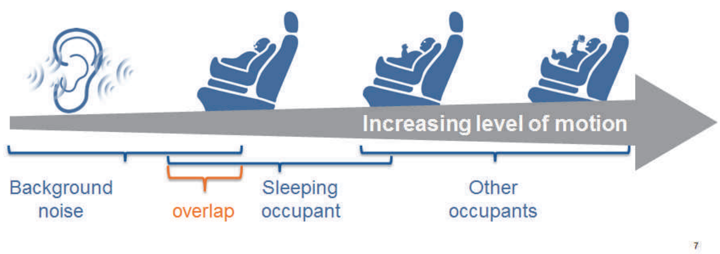

Fig. 3. Schematic of power level for different kinds of occupants and background noise

Nevertheless, the reflected power is not arbitrary as noise but has a phase modulated signal. Thus, the buffered data is analyzed for presence of a periodic motion (breathing) and makes a robust decision possible after 8-10 seconds if the level of power by moving targets is too low and needs to be separated from the background noise. This method is called ”Sleeping Child Recognition”[4].
The following figure 4 shows one example of a one month old baby in a child seat with a closed sunscreen and one example of rain falling onto the empty car, thus increasing background noise.
The pre-processed signal on the left side of the figure shows a periodic signal due to newborn breathing. The ”Sleeping Child Recognition” method detects the regularity and periodicity of

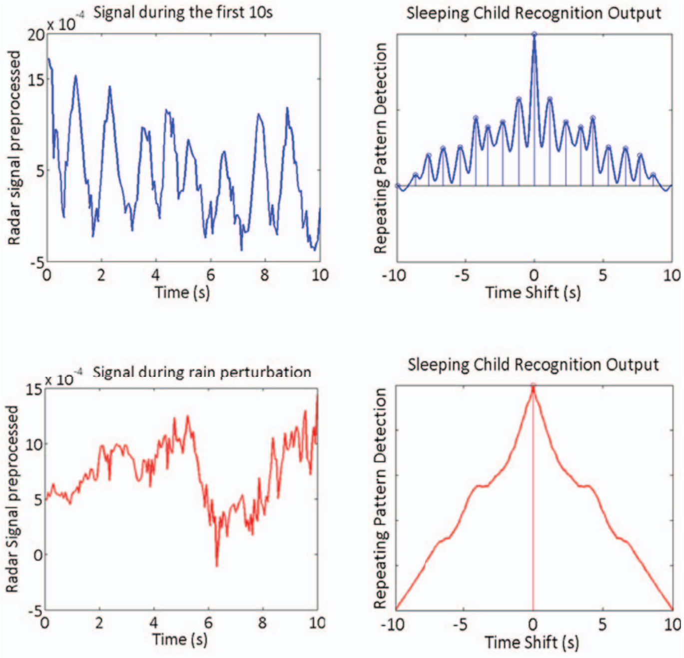

Fig. 4. Raw signal example (left) and processed data (right) of a newborn (blue) and background noise by rain (red)

children breath and classifies the seat as occupied.

The rain yields arbitrary non-constant signals in the pre-processed data with amplitudes comparable or even higher than in the example with the newborn. The "Sleeping Child Recognition" method does not detect any periodicity in the cross-correlation and will classify the seat as "unoccupied"/"empty".

50 newborns were tested for validation which is not a high number in automotive testing. For further testing in the development process a live dummy system has been developed for validation.

IV. IEE Live Dummy

For testing adult and child volunteers could be found easily. The possibility of testing newborns is rare. The tests are quite challenging because the newborns are often not sleeping and moving a lot or even crying which influences the measurement. For repetitive testing, IEE developed a live dummy. The dummy is comprising a newborn-sized baby doll. The size is comparable to newborns requiring class 0 rear-facing children restraint systems. The weight of the doll does not need to be same as a real newborn. The abdomen tissue material is consisting of radar reflective material and a bladder is integrated behind the abdomen tissue in order to simulate breathing. The bladder is connected via a tube to a vacuum pump exciting the bladder to contract cyclically.

Fig. 5 shows the live dummy within a rear-facing children restraint system positioned like a real newborn child. The dummy is connected over the blue tube to the external vacuum pump visible on the right side of the picture. The vacuum pump is not integrated in the doll in order to avoid vibrations resulting from the pump machinery. The pump needs to be located outside the field-of-view of the radar sensor.

Fig. 5. Picture of IEE live dummy in a rear-facing CRS with vacuum pump on the right side

The radar reflective skin tissue of the dummy is limited by size in order to have the same amount of reflected power to the radar reflection of newborns. This has been validated by several monostatic RCS measurements at the IEE test facilities. Figure 6 depicts the pre-processed raw signal of a live dummy measurement. The signal amplitude is comparable in magnitude and shape to the raw signal measurements of real newborn shown in fig. 4

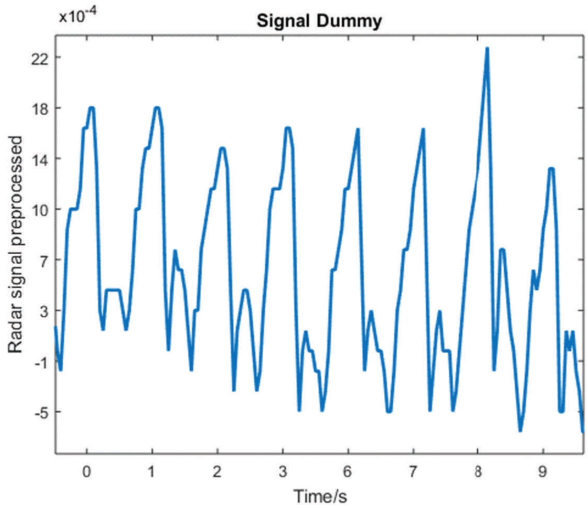

Fig. 6. I-channel raw signal resulting from live dummy measurements

Thus, the IEE live dummy enables the simulation of a "'worst case"' sleeping newborn under repeatable measurement conditions.

V. Conclusion

Firstly, this paper should clarify that children deaths can happen to anyone under distraction and is not related to a certain kind of people. In order to avoid these tragedies the authors presents a robust detection and warning system called VitaSense for left-behind children.

VitaSense is a 24 GHz ISM band motion detector, which is advantageous in comparison to other technologies like optical, infrared or ultrasonic sensors. The sensor detects a wide range of humans in very short time by their breathing. Small newborns which are sleeping can be detected reliably. The sensor is very insensitive to noise and outside influence due to traffic or weather which avoids false alarms.

The testing of the sensor is supported by a live dummy system which simulates a ”worst case” sleeping newborn, and this allows repeatable testing of the sensor.

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