Measurement of a Baby Dummy with a Channel Sounder in an Anechoic Chamber for Child Presence Detection

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Abstract: *The field of applications for ultra-wideband (UWB) radar has been growing in recent years. One interesting use-case is life presence detection, which is detection of living objects – human or animal – in an otherwise static environment. An example is the localization of humans under debris (e.g. after earthquakes). But also, the automotive sector has found use-cases for UWB radars: monitoring of the driver's vital functions or reminding the driver of children or animals left inside, when the user locks the car and walks away. In particular, it is quite a challenge to detect infants in cars within a short period of time. Compared to adults not a lot of measurement data is available regarding Infants. This paper presents a statistical analysis from measurements with a baby dummy in an anechoic chamber.*

1. Introduction

Ultra-wideband (UWB) radars will become a key technology in the automotive sector. One important use-case is the detection of vital signs of humans and animals. This data is primarily used for observing the driver´s conditions, during driving or after an accident, but also for detecting presence of life in a vehicle. Particularly in the case of infants or animals, to avoid locking them unintentionally inside the car [1]-[3].

From 2025 onwards, a Child Presence Detection system will be a European New Car Assessment Programme (Euro NCAP) requirement for new cars. This research project aims to provide fundamental analysis of the problems involved in the task of engineering such systems, allowing the industry to make cars even safer.

Our first step was a model which can be used to estimate the radar responses from a child inside a car environment which was presented in [4]. After finalizing this model, we now tackle another problem, which is the lack of measurement data from infants.

The reason that there is no data is, that it is not ethical acceptable to use infants for such measurement. To overcome this problem, we need to use a dummy like in [5] and [6]. Fortunately, we could partner with 4activeSystems, a company developing such baby dummies. They provided us with one of their prototypes for measurements in our anechoic chamber.

In chapter 2 the different configurations for body movement and respiration simulation of the baby dummy are described. Also, we discuss the restrictions of the baby dummy and their influence. Chapter 3 contains the measurement setup and describes our anechoic chamber.

Problems that occurred during the measurements and how they were solved are also mentioned in this chapter. Chapter 4 discusses the measurement results of the baby dummy and compares the different measurement scenarios. Chapter 5 includes the conclusion and discusses future steps for this research project.

2. Description of the baby dummy from 4active systems

This section describes the different properties and restrictions of the baby dummy and their influence.

In Fig. 1 the baby dummy from 4activeSystems, which represents a one-year-old child, lies in its child´s seat. It consists of the torso, head and limbs, covered by a synthetic skin and filled with a material combination, that imitates the radar properties of the human skin. The control interface of the baby dummy allows four different predefined modes. They define the speed of the limbs and which limbs are moving in the chosen mode. It is possible to further disable single body parts in the selected mode, but it is impossible to enable additional parts. The modes are:

- Deep sleep
- Light sleep
- Wake up
- Awake

The "deep sleep" mode simulates a sleeping baby with only the respiration active. The respiration is simulated by a periodic displacement of the chest. The "light sleep" mode keeps the respiration movement activated, like all other modes and additionally adds sporadic and slow limb movement. In the "wake up" mode also the head is moving and the limbs now move more regularly. Compared to the "wake up" mode, the "awake" mode has faster head and limb movements. The respiration frequency is 31 breaths per minute for all modes.

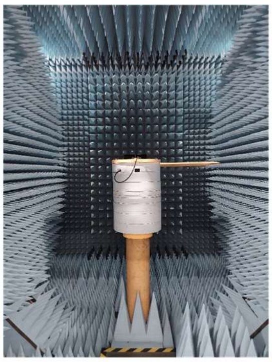
Figure 1. Baby dummy in its child´s seat.

3. Description of the measurement setup

In this chapter the measurement setup is described. Additionally, all the measurement scenarios are listed.

3.1 Anechoic chamber

The chamber has two arms rotatable in the elevation direction, called booms, on which antennas can be mounted. Furthermore, there is a rotary table in the in the centre of the chamber. The booms with the mounted antennas, can sweep over the table with a zenith angle from -120 degrees to 120 degrees, at zero degree the boom is directly above the table. For our measurements only one boom is needed, because of the monostatic radar scenario. The table, represented in Fig. 2 (a), can move from zero to 360 degrees. It has to be mentioned that the mounted baby dummy "looks" to the backside of the anechoic chamber at zero degree azimuth, Fig. 2 (b) illustrates this position.



(a) Table of the empty anechoic chamber

(b) Mounted baby dummy on the table at zero degree azimuth.

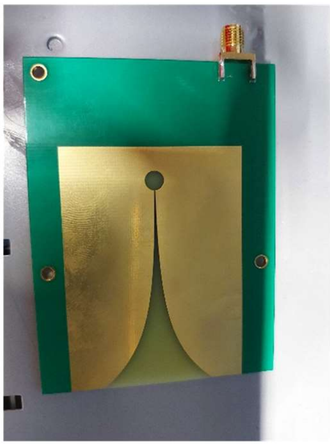
Figure 2. Table of the anechoic chamber, (a) empty chamber, (b) table with the mounted baby dummy at starting position for zero degree azimuth.

3.2 Measurement antennas

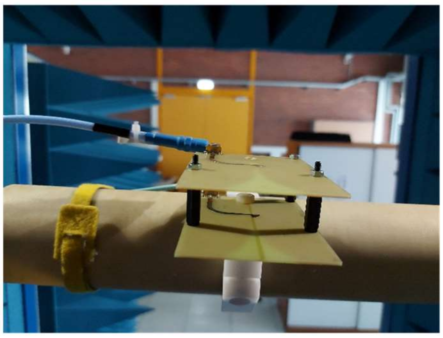
Two Vivaldi antennas are used at one boom, one for transmitting and receiving. Fig. 3 (a) displays one of the Vivaldi antennas and Fig. 3 (b) shows how the antennas are mounted at the boom. This antenna type has been chosen, because it covers the upper UWB frequency bands with a return loss below -10 dB from 5 GHz to 10 GHz, features good gain of about 5 to 6 dBi and is small enough to mount two of them on a single boom.

3.3 Channel sounder

A Channel Sounder is used for the measurements, which is able to measure very fast in the time domain, with 0.1-1 second measurement time. It has two channels, but for our scenarios we only needed one. Furthermore, the frequency range is up to 20 GHz. Before starting measurements with the channel sounder, a calibration is needed, to exclude the internal crosstalk and the transmission lines between the channel sounder and the antennas. After the calibration, we performed a short test measurement in which we encountered a problem with the crosstalk between transmitter- and receiver-antenna. It was too high for the dynamic range of the channel sounder, so that the target reflection from the dummy could not be detected. To solve this problem, we improved the isolation between both antennas, by putting a shielding plane between them.



(a)



(b)

Figure 3. Vivaldi antennas, which are used for the measurement, with the baby dummy, (a) single antenna, (b) Mounted antennas for the monostatic measurement scenario.

3.4 Measurement scenarios

The first measurement scenario is the empty chamber as a reference for post processing. Then the baby dummy both in offline and "deep sleep" mode was measured. The radar response of the dummy was measured in a halfsphere with 10 degrees steps in zenith angle and 15 degrees in azimuth direction. This was chosen to keep the measurement time in an acceptable range. After the halfsphere we measured the other three modes, mentioned in section 2, with fewer selected positions for the azimuth direction (0, 45 and 90 degrees). At last we measured the influence of clothes, in Fig. 4 we see the baby dummy covered with a jacket for this scenario.

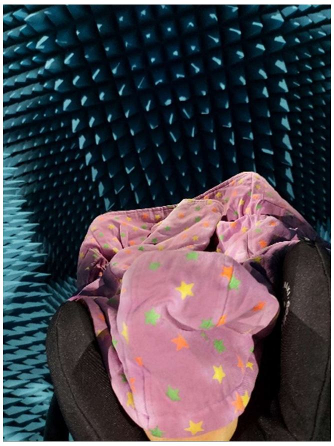
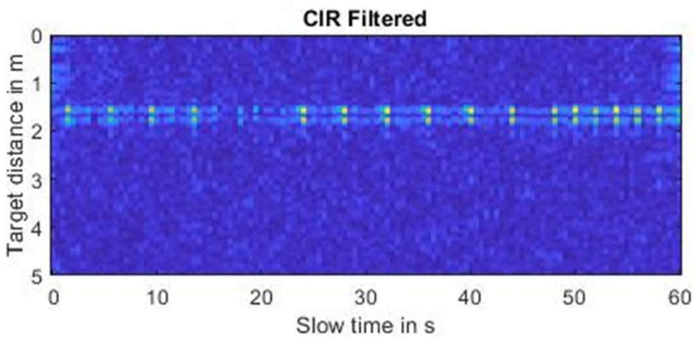


Figure 4. Baby dummy covered with a jacket.

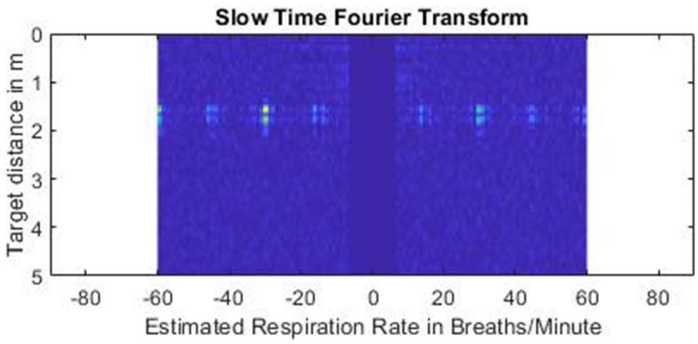
4. Results of the baby dummy measurements

The result section shows and explains the statistical analyses of the measurements with the baby dummy in the anechoic chamber for all scenarios mentioned in the previous section. Important to know is, that the measurement time for every measurement point is one minute, over the full frequency from 1 to 20GHz.

For all measurement points we apply postprocessing to remove the static clutter and make only the moving parts visible. Fig. 5 (a) shows the filtered Channel Impulse response (CIR) for the measurement point of zero degree zenith angle and azimuth in “deep sleep” mode, where the clutter is already removed. We observe, that the baby dummy is one and a half meter away from the receiver and clearly detectable. An unexpected result is the second reflection some centimetre behind the first one. We assume an internal reflection from the stepper motor, which simulates the respiration of the baby dummy. After the removal of the static objects, we transform the measurement data into the frequency domain using Fast Fourier transform (FFT). This is visualized in Fig. 5 (b) as a range-Doppler plot. The respiration frequency of the baby dummy is 31 breaths per minute and this parameter is constant and matches the specification of the dummy.



(a) Measurement of baby dummy with removed static clutter in time domain.



(b) Measurement of baby dummy with FFT in frequency domain.

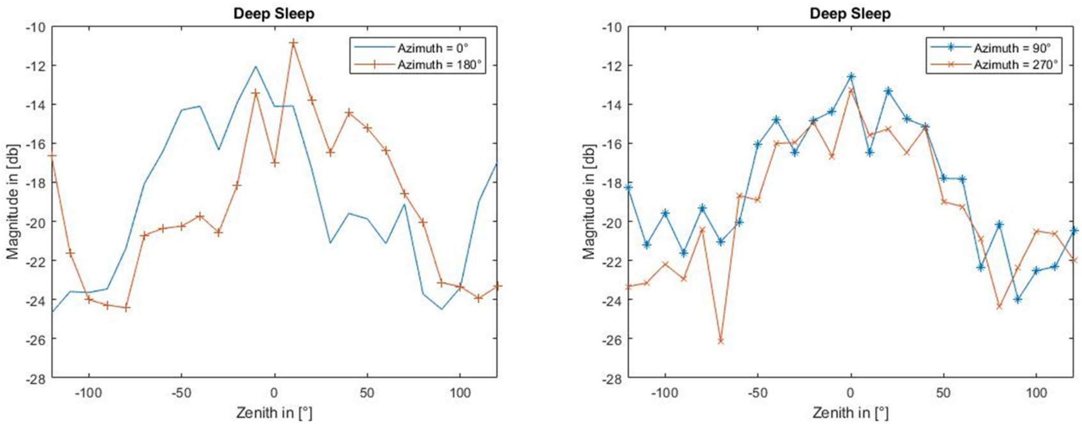
Figure 5. Measurement point at zero degree zenith and azimuth in "deep sleep" mode for the baby dummy, (a) time domain with elimination of static clutter, (b) frequency domain represented as range-Doppler plot.

After the mentioned postprocessing steps, a normalization step is needed to make the different measurements comparable. To achieve this, the highest peak in the range-Doppler plot is used., which came from the "awake" mode measurement.

As a first result Fig. 6 shows the verification of the symmetry of the baby dummy, where Fig. 6 (a) represents the x-axis and Fig. 6 (b) the y-axis. For the y-axis it can be assumed, that the baby dummy is symmetric. While for the x-axis, we must mirror one of the azimuth positions, because for zero degrees azimuth Fig. 6 (b), the antenna starts at the front of the baby dummy and for 180 degrees azimuth it starts at the backside. With this in mind, we can also assume a symmetry for the x-axis. After assuring the symmetry of the baby dummy, for the other modes only a quarter of the sphere needed to be measured.

Next, we compared the four different modes of the dummy. In Fig. 7 (a) the results for the "deep sleep" mode can be seen. The greatest signal power was received, as expected, when the antenna is direct above the baby dummy [7]. We also see a clear strong signal between -70 to 70 degrees zenith angle, outside of this angle the signal amplitude is rapidly decreasing. Fig. 7 (b) "light sleep", (c) "wake up" and (d) "awake" confirm for the other modes, that with more movement the detection becomes easier. It is important to mentioned, that the detected difference in target reflection magnitude between the "deep sleep" and "awake" mode is about 13 dB. This gives us a first indication on how much higher the sensitivity of an UWB radar needs to be to detect an infant which is only breathing compared to one which is moving its limbs.

In Fig. 8 the influence of clothing is seen. While Fig. 8 (a) serve as reference for the baby dummy in “deep sleep” mode, Fig. 8 (b) shows the same measurement now with the baby dummy covered in a jacket. Nearly no influence in the receiving signal can be detected (see also [8]). The increasing signal strength can be explained by the metal zip of the jacket.



(a) (b)

Figure 6. Baby dummy measurement in “deep sleep” mode to check the symmetry, (a) 0 and 180 degrees azimuth, (b) 90 and 270 degree azimuth.

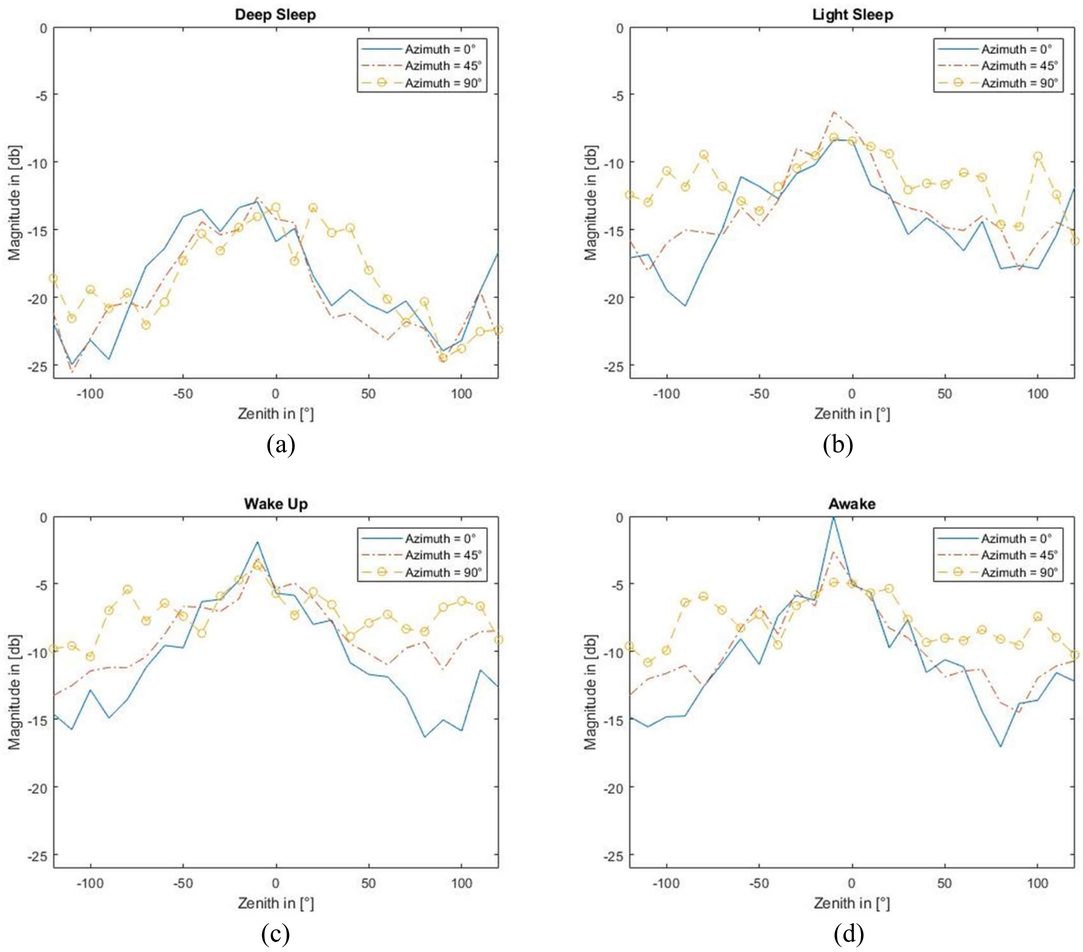
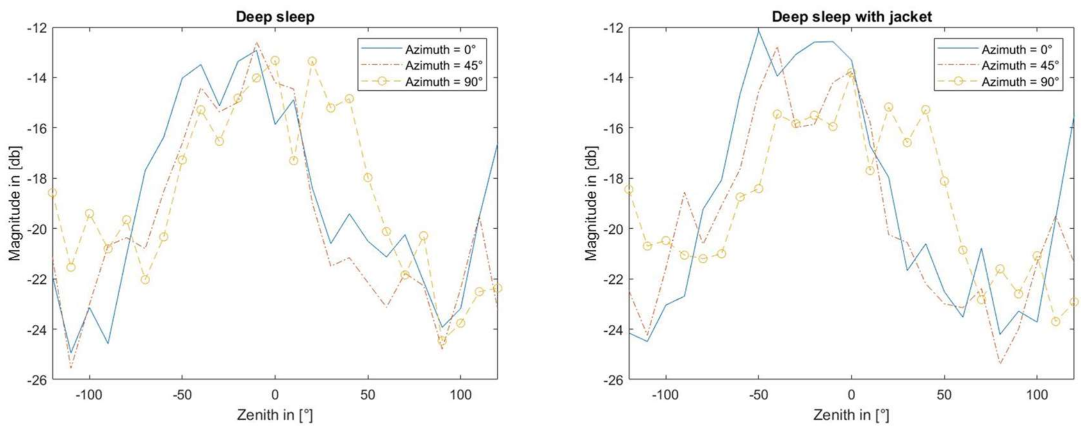


Figure 7. Measurement of selected position of the baby dummy in azimuth direction and ten degrees steps in zenith angle from -120 to 120 degrees of all four different modes, (a) deep sleep, (b) light sleep, (c) wake up, (d) awake.



(a) (b)

Figure 8. Comparison between baby dummy measurement in “deep sleep” mode, (a) without jacket, (b) with jacket.

5. Conclusion

In this paper, we presented a statistical analysis of our measurements with a baby dummy, provided by the company 4active Systems. While for infants a lack of available data exists and measurements with real infants are ethically unacceptable, the surrogate is a good solution to overcome this problem. The properties and restriction of the baby dummy and the core elements from the measurement setup are described. The removal of static clutter and the FFT, are essential postprocessing steps, because for detecting vital signs only the movement is relevant. In the detailed analysis, the importance of the angle in zenith angle and the rapid decrease of the signal strength outside the area between -70 to 70 degrees were discovered. In azimuth direction no favourable angle exists. Furthermore, we confirmed our initial assumption, that the worst-case scenario for detecting vital signs is the instance, where only the respiration is present. Between the most active mode of the baby dummy and the respiration only mode, there is a difference of about 13 dB, which is an important parameter for future work. Clothes can be neglected, or in cases of small metal parts, it can even improve the reflected signal strength.

These measurement data will help us to improve our target model for life presence detection, with the focus on infants of which a first version was presented in [4]. For the future further measurements inside a real car are planned.

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