SHAPE FUTURE

IN THE CENTER OF ECS DEVELOPMENT TO FURTHER BOOST THE TRANSFORMATION OF MOBILITY, TOWARDS ZERO EMISSION & ZERO FATALITIES.

Requirements and Specifications for ECS for Cognition and HMI

Deliverable Lead: BYLO

Deliverable due date: 30/04/25 (M12)

Actual submission date: 29/04/25

Version: v1.0

FUNDED BE THE EUROPEAN UNION

THE PROJECT IS SUPPORTED BY THE CHIPS JOINT UNDERTAKING AND ITS MEMBERS, INCLUDING THE TOP-UP FUNDING BY THE NATIONAL AUTHORITIES OF GERMANY, BELGIUM, SPAIN, FINLAND, NETHERLANDS, AUSTRIA, ITALY, GREECE, LATVIA, LITHUANIA AND TURKEY, UNDER GRANT AGREEMENT NUMBER 101139996-2. CO-FUNDED BY THE EUROPEAN UNION.

Deliverable	D1.2 – Requirements and Specifications for ECS for Cognition and HMI
Work Package(s)	WP1 – Requirements and Specifications
Task(s)	T1.2 – Requirements and specifications for ECS for cognition and HMI
Dissemination Level	Public
Due Date	30-04-2025
Actual Submission Date	29-04-2025
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Document History				
Version	**Date**	**Description**	**Comments**	**Editor(s)**
v0.1	11-04-2025	Draft Release – integrated partner contributions		L. Barberio (BYLO)
v0.3	17-04-2025	Ready for Review		J. Isola (BYLO)
v1.0	29-04-2025	Final version	Moved to new template	J. Isola (BYLO)

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1 Executive Summary

This deliverable showcases the final results of the efforts carried out in the context of ShapeFuture's task 1.2, aimed at the definition of requirements and specifications for the various demonstrators involved in innovation stream 2 (INN2). As the main focus of this innovation stream is to design and develop ECS for cognition and HMI, requirements pertaining to demonstrators from other INNs were also developed, considering they had some components related to INN2's topic.

The main technical considerations are shown in section 5, which gives an overview of each demonstrator, as well as their starting points, the proposed setup, and general objectives.

Section 6 details all the system requirements for each demonstrator in tabular form, including the metrics and rationale used in their design.

Section 7 presents the KPIs of the three demonstrators, a quantifiable measure of performance over time which will ensure the correct validation of the completion of the objectives of each demonstrator and, most importantly, of INN2.

Finally, Section 8 provides information on the state of the art and how each demonstrator will go beyond it, together with a summary of how the work done during this task will have an impact on the rest of the project.

2 Publishable Summary

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3 Introduction & Scope

3.1 Purpose and Target group

Deliverable 1.2 outlines the requirements and specifications for the three demonstrators under INN2. Led by Bylogix, this task (1.2) spans 12 months (M1–M12) and this deliverable is the culmination of all its corresponding efforts.

The demonstrators included are:

- Dem2.1: Compact MEMS Scanner Module
- Dem2.2: Radar Skin
- Dem2.3: Ultra-wideband for Secure Car Access

Furthermore, requirements bearing relation to the context of INN2 (ECS for cognition and HMI), but belonging to demonstrators from other innovation streams, are showcased. This follows the fact that, due to their nature, these specific requirements were developed as part of T1.2, and are the following:

- Dem1.4: Autonomous & Tele-operated Machines with Enhanced Sensors and Haptics
- Dem4.3: Augmented SA in Driving

The target group of this deliverable are the partners involved in the aforementioned demonstrators, as this document will be a point of reference for future development and validation activities. Other project partners and external interested parties may have a look at this document to understand the technical basis and considerations behind the development of some of the technologies which will come out the ShapeFuture project.

3.2 Contributions of partners

Table 1 presents the various contributions of the partners involved in the context of T1.2.

Chapter(s)	Partner	Contribution
5.5, 6.4, 7.5.2, 7.3, 8	EESY	Dem4.3: Augmented SA in Driving Requirements, SOTA, Impacts.
5.3, 6.3, 7.1, 7.2.3, 7.3, 7.4, 8	IFAG	Dem2.3: Ultra-wideband for Secure Car Access Requirements, SOTA, Impacts.
5.1, 6.1, 7.1, 7.2.1, 7.3, 7.4, 8	IFAT	Dem2.1: Compact MEMS Scanner Module Requirements, SOTA, Impacts.
5.2, 6.2, 7.1, 7.2.2, 7.3, 7.4, 8	IMEC	Dem2.2: Radar skin Requirements, SOTA, Impacts.
5.4, 6.4, 7.1, 7.2.4, 7.3, 7.4, 8	SANLAB	Dem1.4: Autonomous & Tele-operated Machines with Enhanced Sensors and Haptics, SOTA, Impacts.

6.1	TOFAS	Dem2.1: Requirements for a vehicular demonstration integrating also the Compact MEMS Scanner Module.

Table 1: Contributions of partners

4 Requirements and Specifications for ECS for Cognition and HMI

4.1 Dem.2.1 Compact MEMS Scanner Module

Overview and Baseline

The primary goal of this Laser Beam Scanning (LBS) demonstrator is to showcase a real-time, FPGA-controlled MEMS-based projection system for automotive applications. The setup proves that a compact 2D MEMS mirror, synchronized with video input, can accurately steer RGB laser beams to project dynamic content onto various surfaces.

IFAT's ambition towards the Compact MEMS Scanner Module is focusing on the following subtopics:

- **Research and development of a novel miniaturized and automotive 2D MEMS mirror**

The 2D MEMS mirror concept represents a core research and development element of the Compact MEMS Scanner Module. It will support two axes which will be operated in an oscillating manner at frequencies of up to 25kHz. Furthermore, an extremely high Q-factor will be achieved via a hermetically sealed package the grants very-low pressure for the oscillating mirror (in the range of several 10k which is unique for a micro-mechanical device), which will reduce power dissipation drastically. This 2D MEMS mirror will enable Lissajous scanning with a field-of-view of at least 15° x 5°, a resolution of >100 pixels per degree and high refresh rate.

- **Development of MEMS Driver Electronics**

A novel MEMS Driver electronics solution will be researched and developed by IFAT. These electronics will not only generate the required voltage for driving the 2D MEMS mirror, but will also sense the 2D MEMS mirror and control it in a synchronized Lissajous manner [1]. Furthermore, apart from, driving, sensing, controlling, and signal processing several novel research ideas will be explored and integrated in order to speed up the starting of the high-Q MEMS mirror.

- **Compact MEMS Scanner Module**

IFAT'S main research and development aims will lead towards the realization of the Compact MEMS Scanner Module. Figure 1 depicts the concept study of such a novel module. It will integrate the 2D MEMS mirror, the MEMS Driver electronics, and all required discrete components into a single module.

- **Laser Beam Scanning demonstrator**

In order to showcase the partners' achievements, a Laser Beam Scanning demonstrator will be assembled towards the end of the funded project. This demonstrator will combine the Compact MEMS Scanner Module with a Display FPGA, lasers, laser drivers, and optics in order to demonstrate the achieved performance of IFAT's laser beam video projection solution (i.e., resolution, refresh rate, projection stability), and the achievable superior form factor.

IFAT developed some baseline technologies during former projects PRYSTINE and NewControl. During these projects a 1D MEMS and sensing circuitries were developed with a focus on LiDAR sensors. During ShapeFuture, the complexity is brought to a next level by developing a highly complex (from a mechanical point of view) 2D MEMS mirror, as well as sensing, control, and synchronization circuitries. Furthermore, the targeted use-cases, dynamic ground projection and dynamic interior projection, are completely different to LiDAR and lead to additional requirements and complexity (e.g., requirement for a 2D MEMS mirror instead or a 1D MEMS mirror). Therefore, only some basic know-how can be regarded as baseline for the Compact MEMS Scanner Modules.

Technical Considerations

A high-level setup diagram of the final Laser Beam Scanning demonstrator is provided by Figure 1. The Compact MEMS Scanner Module takes care about sensing and controlling the 2D MEMS mirror and provides crucial MEMS position data to a Display FPGA. When addressing the use-case AR HUD, this Display FPGA identifies itself as a typical display to a standard laptop and receives an HDMI video input stream. Therefore, video streaming content can be generated very conveniently. Dynamic ground/interior projection use-cases store the video to be projected inside the Display FPGA/electronics. The Display FPGA uses the video input stream and the MEMS position data in order to trigger the RGB lasers at the correct points in time. The laser beams will be deflected by the 2D MEMS mirror into the scenery. Depending on the actual application, the laser beams either is projected onto the street, an interior surface, or fed into fibres (AR HUD).

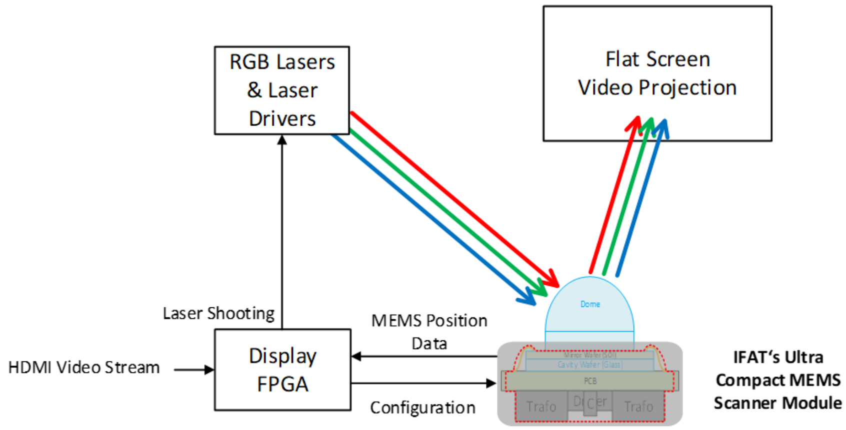


Figure 1: Setup of IFAT's LBS demonstrator

4.2 Dem2.2 Radar Skin

Overview and Baseline

The aim of the "Radar skin" demonstrator is to show the possibilities of a distributed radar system. Distribution of radar sensors over the body of a car enables a very wide field of view and will allow for accurate detection of objects surrounding the vehicle in position, distance and speed. The demonstrator will focus on the physical buildup of the system as well as the required processing algorithms.

More specifically, the goal is to develop a distributed radar system, that uses multiple SISO radar nodes distributed over the "skin" of a car instead of the classical approach where complex MIMO radar sensors are placed on well-defined locations on a car. Classically Long-Range Radars are placed in the center of the front grill of a car and radars for Blind Spot Detection are placed at the corner of the bumper. These classical MIMO radars have their own radar processing of which data could be merged later in a central ECU. Our approach is to use many small FMCW 140 GHz SISO radar sensors and distribute them over the bumper of the car. The advantage of using 140 GHz for the radar sensors are:

- **Higher resolution:** enabling the detection of smaller objects and improving the detection of objects at various distances and angles.

- **Smaller antennas:** this is particularly beneficial for automotive design, where compactness and maintaining a sleek appearance are critical.

By distributing the radar sensors over the car bumper, a very large radar aperture is created allowing for a very fine angular resolution. A distributed radar "skin" approach will eventually allow full 360° field of view when the radar nodes are distributed on all sides of the car.

To allow for coherent processing of the radar signals, all sensors should receive the same FMCW chirp. An optical distribution will be used to distribute a 16GHz chirp to the different sensors. This allows covering very large distances with minimal loss and accurate synchronization between the radar sensors.

Radar processing will be done at a central node and both coherent and non-coherent signal processing will be explored. New radar processing algorithms will be developed, and performance will be compared with the classical solutions. As the output power of our available 140GHz radar sensors is limited, for the demonstrator we will only focus on short range scenarios like autonomous parking.

The 140 GHz TX-, RX-chips and 16GHz chirping PLL that will be used can be seen in Figure 2 have been developed within Imec in 28nm CMOS technology and will serve as a baseline for the "Radar Skin" demonstrator.

Figure 2: 140 GHz TX-, RX-chips and 16GHz chirping PLL

Technical Considerations

The initial block diagram for the Demo 2.2 "Radar Skin" demonstrator is shown in Figure 3. It shows the distributed radar sensors based on Imec's developed 140GHz radar chips, the optical distribution of a 16GHz FMCW chirp generated at a central PLL and the central radar processing.

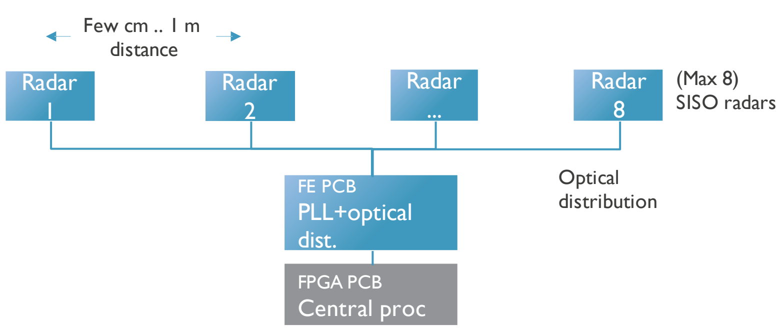


Figure 3: Demo 2.2 "Radar Skin" block diagram

The envisioned demonstrator will be a lab substitute for a car bumper with distributed radar sensors. A picture of a possible use case is depicted in Figure 4.

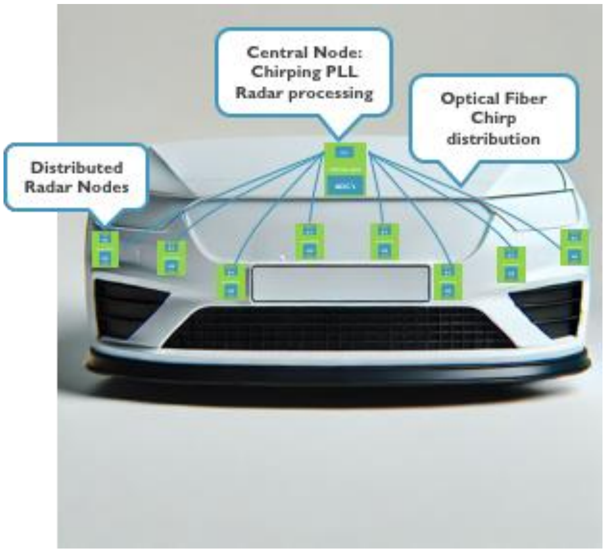


Figure 4: "Radar Skin" Distributed Radar Sensors

4.3 Dem2.3 Ultra-wideband for Secure Car Access

Overview and Baseline

Although early-generation UWB-based secure-ranging hardware recently has already been integrated into smartphones, they partly use different earlier versions of standards (FiRa or related), and partly are not sufficient for the car-access application targeted in Dem 2.3. Some of today's early-generation hardware-systems are not yet optimized for low-power operation. This has an environmental impact as it increases the number of batteries required for car-access key-fobs and additionally strains the car battery of an EV. One identified key contributor to high power consumption is the long synchronization frame in the PHY packet required to synchronize both transceivers. Thus, in the new-generation chip-development, IFAG incorporates concepts to improve active and standby power consumption over current state of the art UWB systems, considering both, HRP and LRP radio pulse modes, to allow for optimized usage in different use-cases (e.g. car-side and key-fob). Furthermore, early-generation UWB-based hardware partly lacks the higher-protection-level for keys and cryptographic operations, such as provided by state-of-the-art secure elements. Therefore, as part of the firmware- and system-integration work, IFAG will combine the UWB-radio hardware with appropriate hardware-based security measures into an overall Secured-UWB system. This will be the basis for the Dem 2.3 proof-of-concept demonstrator (to be evaluated in an appropriate lab-setup).

The baseline for the Dem 2.3 developments is Infineon's existing, early-generation UWB IC 3DB6830 [12], which is an impulse radio UWB-based transceiver in the upper UWB bands from 6 to 8 GHz. It is IEEE 802.15.4f compatible and meets ETSI and FCC Part 15.250 regulations. This IC performs a true direct Time-of-flight (ToF) distance measurement using radio frequencies (RF). The RF pulses allow maximizing the energy per pulse at the transmitter which is crucial since it allows to reduce the complexity of the receiver for a given distance range. Since this chip also includes a formally proven purpose-built MAC layer for secure distance bounding and data communication, this first-generation IC is the perfect starting-point as analog- and digital front-end for further new SoC chip-integration developments targeted in the scope of this project by project partners IFAG and IFAT.

Technical Considerations

The envisioned general usage-scenario of Dem 2.3 is depicted in Figure 5: One of the developed UWB-systems would be either integrated into a battery-powered key-fob or in a smartphone device, the other UWB-system integrated into a car (note: in the context of this project the UWB-system will be actually shown as proof-of-concept lab-demonstrator instead of a real car). With this setup, besides the classical cryptographic authentication via wireless channel, the UWB communication is used to locate the key-fob with a precision of 10cm, in order to verify the physical presence of the key (and thereby preventing relay-attacks).

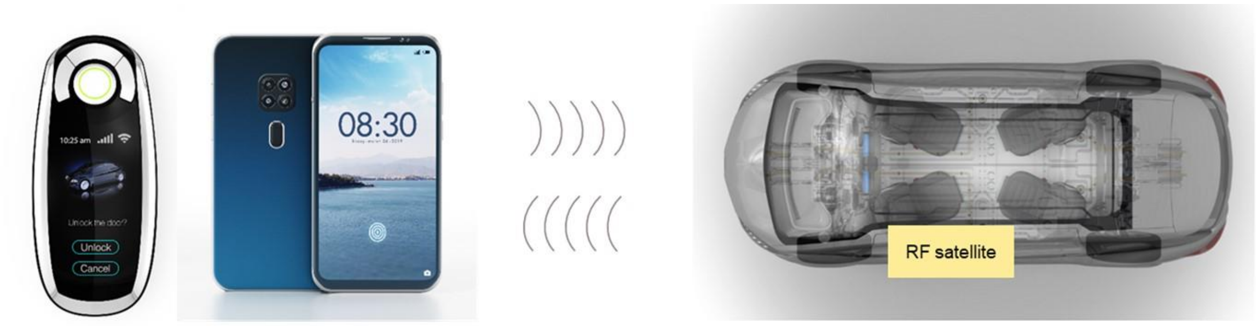


Figure 5: Envisioned UWB-based secured-car-access demo

Finally, the targeted overall "car-access sub-system" – developed in cooperation by IFAG and IFAT – is shown a high-level block diagram in Figure 6. The system combines three chips as the main-components: UWB-radio for the precise ranging/localization, BLE for the required out-of-band channel, and the Secure-Element (SE) for providing hardware-based security protection. Furthermore, the system also considers using NFC as fallback-channel (e.g. to be used in the case of an empty battery of the key-fob or smartphone).

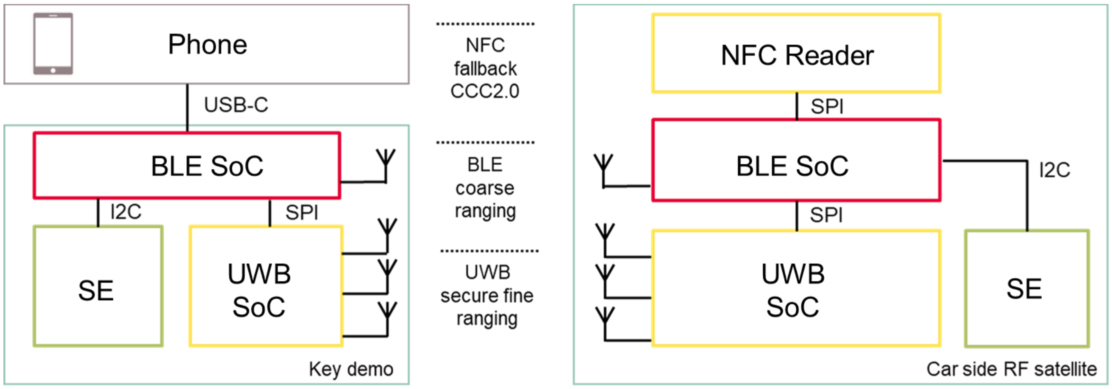


Figure 6: High-level block diagram of targeted overall car-access sub-system

4.4 Cross-Innovation Stream - Dem1.4 Autonomous & Tele-operated Machines with Enhanced Sensors and Haptics

This chapter describes Dem1.4's partial contribution to INN2, limited to cognition and HMI-related requirements for this demonstrator; for a full description of the following demonstrator's contribution, please refer to the corresponding deliverable (D1.1).

Overview

Sanlab will develop haptic technologies (joystick and vest) for remote control of the excavator simulator in collaboration with SMRT. This project aims to create a more interactive Human-Machine Interface (HMI) for controlling earthmoving machines and robots. Haptic joysticks will provide precise tactile feedback and enhance control using actuators such as piezoelectric, linear resonance actuators (LRA) or eccentric rotating mass (ERM) motors.

Additionally, adaptive noise cancellation techniques will be applied to improve the quality of the audio data received from the system's microphones. This will improve the integration of sensor data and increase the operator's environmental awareness. The system will create a virtual environment using data from cameras and other sensors, and will provide more information to the operator by improving haptic feedback with real-time 3D simulations.

The development process will ensure that the haptic joystick and vest software work together in harmony. This will involve processing sensor data, generating appropriate haptic feedback, and managing communication with machines or robots.

Technical Considerations

The Figure 7 below describes the system topology and general solution approach.

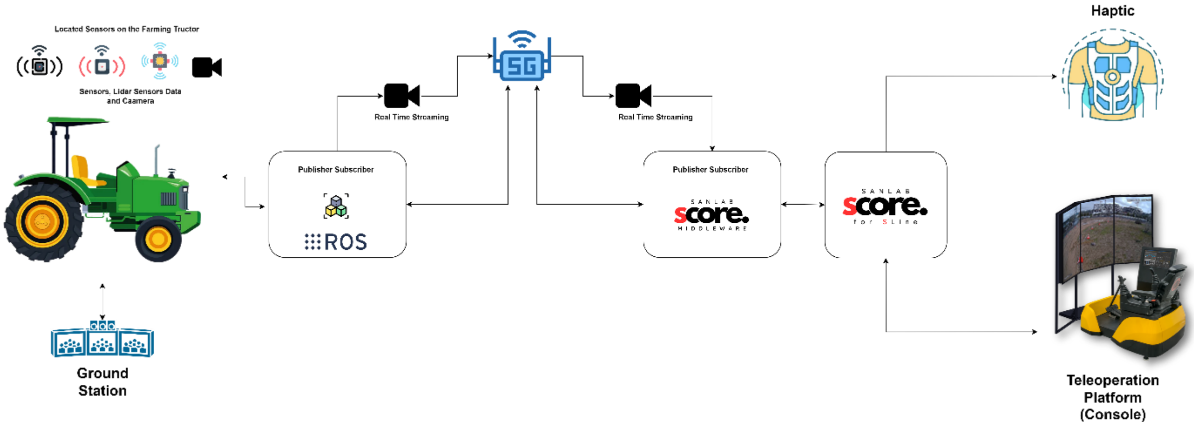


Figure 7: SANLAB functional block diagram

4.5 Cross-Innovation Stream - Dem4.3 Augmented SA in driving

The following chapters describe Dem4.3's partial contribution to INN2, limited to cognition and HMI-related requirements for this demonstrator; for a full description of the following demonstrator's requirements, please refer to the corresponding deliverable (D1.4).

Overview

The high-level use case for Demonstrator 4.3 is when a vehicle moves in a local, limited area with other vehicles and vulnerable road users that are hidden by obstacles or fixed buildings. The driver will be provided with an onboard display with an occlusion-free panoramic view of the surrounding environment with traffic alerts that aims at improving the driver's field-of-view (FOV). This demonstrator is separated into three categories, 1) on board, 2) edge cloud, and the 3) environment. In 1) data is gathered from the visual and depth sensors of the vehicle. This data is further processed using sensor fusion, panoramic stitching, and blind spot annotation. The captured and processed data can then be provided directly to the driver using the vehicle's internal networking to provide ultra-low latency augmented information about the vehicle's environment. This same data is then transmitted from 1) to 2) using a cellular connection to the edge cloud (LAN/Wi-Fi can also be used in the laboratory setup). For reduced bandwidth, the visual data is compressed using visual data compression for machines and humans to suit both AI and human consumption of the data. In 2) the edge cloud's processing power is utilized for running more demanding algorithms for the incoming data from vehicle(s). These algorithms include cognitive scene understanding, driving and traffic analysis, and virtual occlusion removal with view synthesis. In addition to data coming from vehicle(s), the data can be further gathered from 3) where environmental sensors are used for possibly providing better view of the scene in a limited area. The data transmissions from 3) to 2) and from 2) to 1) are closely related to the connection from 1) to 2).

The main goal of the onboard blind spot annotation functionality is to improve driving safety by indicating the most significant nearby blind spots in real time. Blind spots are locations that are not visible to the driver but may hide other traffic participants impacting the driving environment. At the same time, this demonstrator also aims at improving the cognitive scene understanding of the driver by combining an annotated visual data stream from vehicle onboard processing with information from external sensors to form a more comprehensive view of the traffic environment. The main purpose is to extend the driver's situational awareness from imminent risks (such as the blind spots detected and annotated onboard) to a wider view, both spatially and temporally.

Technical Considerations

The initial high-level design of Dem4.3 is shown in Figure 8. The figure also showcases the distribution and up-coming contribution of partners involved in Dem4.3 with the designated number per partner shown in the legend. This initial design and partner contribution allocation might still change during WP2 and the system level design, but the design will be updated in the upcoming deliverables accordingly.

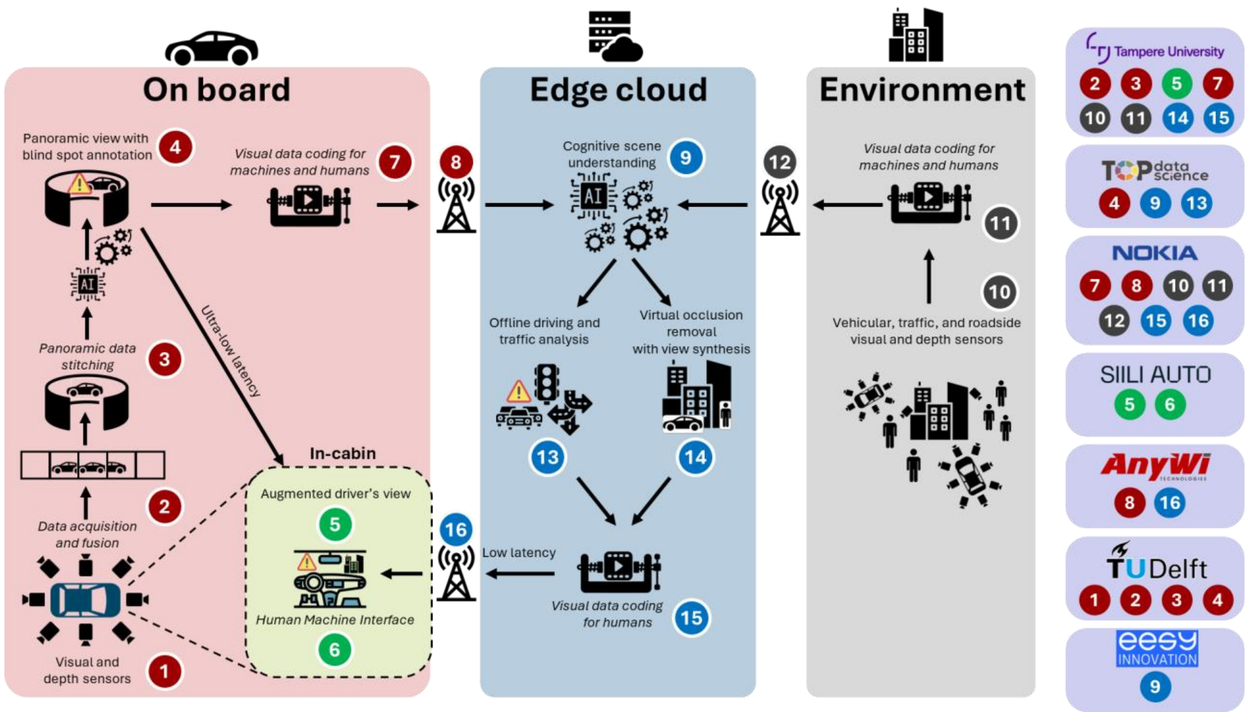


Figure 8: Initial high-level design of Dem4.3 with the contribution list from partners

5 Project Requirements

What follows is a list of all the requirements pertaining to the demonstrators shown in section 5. They cover either functional or performance aspects of the developed technologies, and are divided in per-demonstrator subsections for readability. A separate database in Excel format containing all these requirements is kept in the project's internal cloud for ease of access of the involved partners.

5.1 Dem2.1 Requirements

ID:	**REQ_WP1_T1.4_DEM2.1_1**
Name:	LBS demonstrator
Description:	There shall be an LBS demonstrator that shall project a video stream into the scenery
Rationale:	Most basic setup
Metrics:	Implementation and testing of the demonstrator
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_2**
Name:	LBS demonstrator performance resolution
Description:	The demonstrator shall support more than 600x400 pixel and a configurable Lissajous frame rate
Rationale:	Demonstrator KPI
Metrics:	Verification of demonstrator
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_3**
Name:	LBS demonstrator partitioning
Description:	The demonstrator shall be partitioned into a scanner module, a picture generation unit, and the laser module
Rationale:	Enables easy exchanging of future hardware updates

Metrics:	Implementation of the demonstrator
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_4**
Name:	LBS demonstrator laser module
Description:	The module shall contain lasers, laser drivers, and optics for laser projections
Rationale:	Basic module setup
Metrics:	Implementation of the module
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_5**
Name:	LBS picture generation unit
Description:	There shall be an FPGA-based picture generation unit that receives a video stream via HDMI or uses pre-stored video stream to be projected into the scenery by means of the scanner and laser modules
Rationale:	Basic functionality of the PGU
Metrics:	Running and testing the LBS demonstrator
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_6**
Name:	LBS scanner module
Description:	The scanner module shall sense and drive the MEMS mirror and shall provide the position information of the MEMS
Rationale:	Basic functionality of the scanner module
Metrics:	Running and testing the scanner module

Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_7**
Name:	LBS scanner module MEMS
Description:	The scanner module shall feature a 2D MEMS mirror of >1mm diameter and >5° oscillation angle
Rationale:	MEMS requirements
Metrics:	Verification of the MEMS
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_8**
Name:	LBS scanner module driver
Description:	There shall be driver electronics that sense and control the position of the 2D MEMS mirror
Rationale:	Driver requirements
Metrics:	Verification of the driver electronics
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_9**
Name:	LBS scanner module performance pointing stability
Description:	Standard deviation of pointing stability shall be <5mdeg
Rationale:	Scanner module KPI
Metrics:	Verification of the scanner module
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_10**

Name:	LBS scanner module performance amplitude stability
Description:	Standard deviation of amplitude stability shall be <5mdeg
Rationale:	Scanner module KPI
Metrics:	Verification of the scanner module
Owner:	IFAT

ID:	**REQ_WP1_T1.4_DEM2.1_11**
Name:	Environmental Durability of IFAG MEMS Scanner for ATT and vehicles
Description:	MEMS scanner must operate reliably under varied weather and environmental conditions typical to towing operations.
Rationale:	Ensures uninterrupted sensor performance under harsh conditions such as rain, dust, or vibrations.
Metrics:	Operational temperature -20°C to +60°C, IP67 rated enclosure, vibration resistance per ISO 16750
Owner:	TOFAS

6.2 Dem2.2 Requirements

ID:	**REQ_WP1_T1.4_DEM2.2_12**
Name:	Distributed radar system
Description:	Distributed radar system that consists of several individual SISO radar nodes that are spaced multiple lambdas apart
Rationale:	Huge MIMO radars are technically not feasible, that's why distributed SISO nodes are used
Metrics:	Physical buildup of the demonstrator
Owner:	IMEC

ID:	**REQ_WP1_T1.4_DEM2.2_13**
Name:	The spacing between the outer nodes should be at least 1 m

Description:	To demonstrate the scalability of the "Radar Skin", a 1 m distance is seen as a good compromise for a practical demonstrator setup.
Rationale:	This will enable to demonstrate the difference between a conventional MIMO radar and a distributed radar
Metrics:	The distance between the outer nodes should be at least 1 m on the physical demonstrator
Owner:	IMEC

ID:	**REQ_WP1_T1.4_DEM2.2_14**
Name:	Minimum of 4 radar nodes with angle between nodes
Description:	A "Skin" can have a random shape, this results in radar nodes that are not necessarily placed in a line.
Rationale:	Allows to have a wide field of view.
Metrics:	Physical buildup of the demonstrator should have at least 4 nodes placed under an angle
Owner:	IMEC

ID:	**REQ_WP1_T1.4_DEM2.2_15**
Name:	Coherently distributed radar signal
Description:	The radar signal (FMCW chirp) will be distributed coherently from the central node to the different radar nodes
Rationale:	Allows to use of the bistatic part of the transmitted radar signals
Metrics:	Architecture for coherent signal distribution to the different nodes
Owner:	IMEC

ID:	**REQ_WP1_T1.4_DEM2.2_16**
Name:	Algorithm to use the bistatic radar information
Description:	Every SISO radar node receives the transmitted signals from neighbouring nodes. An algorithm will allow to use this signal in a meaningful way.

Rationale:	Will enable better resolution
Metrics:	Algorithm available
Owner:	IMEC

ID:	**REQ_WP1_T1.4_DEM2.2_17**
Name:	X-Y map of at least 2 targets
Description:	An X-Y map of at least 2 targets will be created based on triangulation
Rationale:	Shows the ability to map objects in a 2-demensional space
Metrics:	Demonstrator outputs X-Y target map
Owner:	IMEC

ID:	**REQ_WP1_T1.4_DEM2.2_18**
Name:	Metric to compare to MIMO system with same number of TRXs
Description:	A metric will be defined to compare the performance of a distributed radar system with a traditional MIMO radar with the same number of transmitters and receivers
Rationale:	Allows to compare a distributed radar with a traditional MIMO radar
Metrics:	Metric available
Owner:	IMEC

6.3 Dem2.3 Requirements

ID:	**REQ_WP1_T1.4_DEM2.3_19**
Name:	MCU subsystem
Description:	The UWB SoC shall implement an MCU subsystem which enables autonomous operation of the UWB ranging on the anchor.
Rationale:	UWB anchors are placed on different positions of the car and a dedicated MCU subsystem allows the UWB SoC to work

	independently of other HW components and reduces overall system cost.
Metrics:	Verifiable CPU subsystem available with sufficient performance for secure ranging and required post processing
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_20**
Name:	Power Consumption
Description:	The UWB SoC shall implement a UWB transceiver with low power consumption.
Rationale:	Low active power consumption of the UWB SoC is critical to ensure little strain on internal battery of the car and enable operation of the key fob.
Metrics:	Active Tx power consumption <50mA and Rx power consumption <100mA averaged in a ranging session.
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_21**
Name:	Security
Description:	The UWB SoC shall be capable of executing code in a secure environment.
Rationale:	For secure FW update and processing of the Secure Timestamp key the UWB SoC needs to be able to protect these assets.
Metrics:	TrustZone as part of CPU subsystem implemented
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_22**
Name:	Package
Description:	The UWB SoC shall be integrated into a package suitable for automotive assembly and quality needs.

Rationale:	The automotive industry has strict quality requirements and stringent qualification processes.
Metrics:	Package requirements for automotive met
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_23**
Name:	Memory
Description:	The UWB SoC shall implement a non-volatile memory for autonomous operation of UWB secured ranging on the nodes.
Rationale:	UWB anchors are placed on different positions of the car and a dedicated MCU subsystem allows the UWB SoC to work independently of other HW components and reduces overall system cost.
Metrics:	NVM with sufficient size to store customer code and allow UWB operation available
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_24**
Name:	Firmware
Description:	The UWB SoC shall implement a MAC layer suitable for a car access use case.
Rationale:	Several UWB anchors are distributed among the car and require coordinated scheduling to perform ranging with a phone/key fob that is approaching.
Metrics:	The UWB SoC is capable of executing a Car Connectivity Consortium (CCC) Medium Access Control (MAC) layer
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_25**
Name:	Transceiver

Description:	The UWB SoC shall implement a UWB transceiver capable of 4z-compliant ranging with phones.
Rationale:	Phone as a key is a major driver for UWB adoption for car access and phones are following the High Rate Pulse (HRP) repetition frequency mode of the 4z UWB standard.
Metrics:	The UWB SoC is interoperable with at least one smartphone showcasing interoperability with the smartphone ecosystem.
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_26**
Name:	System Integration
Description:	The UWB SoC shall be integrated into the host system which allows to exchange parameters for the UWB session setup.
Rationale:	UWB SoCs are not allowed to be always on, therefore another mechanism (Out-of-Band (e.g., Bluetooth)) is required to detect UWB devices in the vicinity.
Metrics:	A host system can detect another host system for session setup
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_27**
Name:	Digital Key applet
Description:	The UWB SoC shall operate with Secure Element (SE) - based transaction mechanisms to communicate with a digital key applet which protects required key material.
Rationale:	Key material needs to be stored protected in Trusted Execution Environment (TEE) or Secure Element (SE) for high security.
Metrics:	Keys are stored in a protected environment
Owner:	IFAG

ID:	**REQ_WP1_T1.4_DEM2.3_28**
Name:	Host to FiRa-Standard "UWB Subsystem" API

Description:	The API between the host shall use the FiRa-Standard "UWB Command Interface" as a standardized interface to allow flexibility and testing of each system component
Rationale:	Improves flexibility of system design and verification
Metrics:	The FiRa-Standard "UWB Subsystem" is testable via the standardized interface
Owner:	IFAG

6.4 Cross-Innovation Stream Requirements

Dem1.4 Requirements

ID:	**REQ_WP1_T1.4_DEM1.4_29**
Name:	Haptic vest - controllability
Description:	A haptic vest that can be controlled by software shall be available for the tele-operator
Rationale:	Operator needs it to for Teleoperation
Metrics:	Operator interacts excavator through the vest
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_30**
Name:	Haptic vest - ease of use
Description:	Vest shall be easily wearable and the haptic devices shall cover the operators' body
Rationale:	Different operators might need it to for Teleoperation
Metrics:	Must fit for at least 2 different tele-operator body sizes
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_31**

Name:	Haptic joystick - controllability
Description:	Haptic joysticks that shall be controlled by software shall be available for the tele-operator
Rationale:	Operator needs them to for Teleoperation
Metrics:	Operator interacts excavator through the joysticks
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_32**
Name:	Haptic joystick - big analogue stick
Description:	Each joystick shall have at least one analogue stick with four directions; left, right, forward, backward
Rationale:	Operator needs those options for Teleoperation
Metrics:	GCS data shows 16bit precision control at each direction.
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_33**
Name:	Haptic joystick - small analogue stick
Description:	Each joystick shall have at least one additional smaller analogue stick with two directions; forward, backward
Rationale:	Operator needs those options for Teleoperation
Metrics:	Precision GCS data shows 16bit precision control at each direction.
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_34**
Name:	Haptic joystick - digital interface
Description:	Each joystick shall have at least ten digital buttons

Rationale:	Operator needs those options for Teleoperation
Metrics:	GCS data shows use of each button.
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_35**
Name:	Excavator Console - fitting
Description:	There shall be a System design for haptics (haptics on joystick and vest) for enhanced HMI of teleoperation excavator console.
Rationale:	Haptics hardware needs to fit Excavator Console
Metrics:	Consideration of dimensions for computer, hardware and visual systems
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_36**
Name:	Computing Systems and Algorithms
Description:	There shall be Develop Adaptive noise cancellation techniques shall be implemented to improve the quality of audio data captured by the system's microphones.
Rationale:	Adaptive Noise Cancellation is needed for comfort of the operator
Metrics:	Signal to Noise Ratio (SNR): 30db Delay: 30sm (*It refers to the input-output time during which the Noise Cancellation Algorithm processes the audio data)
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_37**
Name:	System Software Architecture

Description:	Software will be developed with the haptic vest software, ensuring seamless interaction between the two systems.
Rationale:	Middleware Software Development
Metrics:	This includes processing sensor data, generating appropriate haptic feedback, and managing communication with the machines or robots.
Owner:	SANLAB

ID:	**REQ_WP1_T1.4_DEM1.4_38**
Name:	Real-Time 3D Simulation
Description:	System will enable Real-time 3D simulations to be applied to create a virtual representation of the environment based on the data captured by cameras and other sensors.
Rationale:	Real-Time Simulation is needed for virtual representation.
Metrics:	Present a virtual representation of the environment based on the data captured by cameras and other sensors.
Owner:	SANLAB

Dem4.3 Requirements

ID:	**REQ_WP1_T1.4_DEM4.3_39**
Name:	AI algorithm using LiDAR and camera
Description:	As minimum sensors, the AI pipeline has to include LiDAR and camera sensor data to ensure a correct detection of targets in all light conditions.
Rationale:	Ensure the correct functionality of the algorithm in all the relevant conditions for the project.
Metrics:	LiDAR and camera sensor data used in the algorithm
Owner:	EESY

ID:	**REQ_WP1_T1.4_DEM4.3_40**

Name:	Reduced algorithm latency at the network edge
Description:	The developed AI algorithm for target detection should take less than 100 ms for its execution in the selected edge platform for the demo.
Rationale:	Optimization for real time constraints
Metrics:	Latency under 100 ms
Owner:	EESY

ID:	**REQ_WP1_T1.4_DEM4.3_41**
Name:	Desired targets for the application
Description:	The AI algorithm should detect at least pedestrians, cars, motorbikes, bicycles and trucks with more than a 70% of mAP.
Rationale:	Minimum targets to ensure its capabilities in a real scenario
Metrics:	mAP for each of the desired target classes over 70%
Owner:	EESY

ID:	**REQ_WP1_T1.4_DEM4.3_42**
Name:	AI algorithm size
Description:	To ensure its optimization for the network edge, the algorithm must not have more than X parameters.
Rationale:	Validation of the model size optimization
Metrics:	Model must have less than 25 million parameters.
Owner:	EESY

ID:	**REQ_WP1_T1.4_DEM4.3_43**
Name:	AI algorithm robustness

Description:	The algorithm should be robust to sensor failure, so even in case one of the sensor data is not available the mAP should stay over 35%.
Rationale:	Validation of system robustness
Metrics:	mAP when sensor failure should be over 35%
Owner:	EESY

ID:	**REQ_WP1_T1.4_DEM4.3_44**
Name:	AI algorithm validated in public datasets
Description:	To ensure the performance of the algorithm, it should be evaluated in the KITTY and NuScenes public dataset.
Rationale:	Validation of the system performance
Metrics:	Model performance in KITTY and NuScenes datasets (based on LiDAR and camera)
Owner:	EESY

ID:	**REQ_WP1_T1.4_DEM4.3_45**
Name:	Algorithm must accept data from simulation environment of Dem4.3
Description:	The algorithm should include the corresponding interfaces to accept the data from the simulated virtual environment of Dem4.3.
Rationale:	Validation of system interfaces
Metrics:	Interfaces defined and integrated
Owner:	EESY

6 KPIs

The following is a list of KPIs which will be used to measure the degree of completion and achievement of the various targets set by each demonstrator, in a more quantitative way. This will hopefully lead to better focusing of development efforts during the project and, therefore, more tangible results.

6.1 Dem2.1 KPIs

Name:	LBS scanner module performance pointing stability
Description:	Standard deviation of pointing stability shall be < 5mdeg
Unit:	mdeg
Type:	Numeric
Weight:	1
Trend in Literature:	Not disclosed by competitors. <5mdeg is a very demanding KPI required by potential key customers.
Test Environment:	Test is executed with the help of a dedicated optical test bench. The pointing stability of the center- and a border-pixel are evaluated.

Name:	LBS scanner module performance amplitude stability
Description:	Standard deviation of amplitude stability shall be <5mdeg
Unit:	mdeg
Type:	Numeric
Weight:	1
Trend in Literature:	Not disclosed by competitors. <5mdeg is a very demanding KPI required by potential key customers.
Test Environment:	Test is executed with the help of a dedicated optical test bench. The amplitude stability of a border-pixel is evaluated.

6.2 Dem2.2 KPIs

Name:	Distributed Radar
Description:	Radar system with at least 4 radar nodes spaced several lambdas apart with at least 1m between the outer nodes.
Unit:	Yes/No
Type:	Boolean
Weight:	1
Trend in Literature:	Not disclosed by competitors.
Test Environment:	Radar will be tested in a lab environment with the radar nodes placed on a dedicated custom build setup.

Name:	Target mapping
Description:	Map at least 2 targets in a XY-map.
Unit:	Yes/No
Type:	Boolean
Weight:	1
Trend in Literature:	Not disclosed by competitors.
Test Environment:	Radar will be tested in a lab environment with the radar nodes placed on a dedicated custom build setup and targets will be corner reflectors.

6.3 Dem2.3 KPIs

Name:	Power Consumption
Description:	The UWB SoC shall implement a UWB transceiver with power consumption <100mA (averaged in a ranging session)
Unit:	mA
Type:	Numeric
Weight:	2
Trend in Literature:	Not disclosed by competitors.
Test Environment:	Lab environment, running typical UWB-ranging session (locating the key-fob), in parallel measuring power-consumption

Name:	Security execution
Description:	The UWB SoC shall be capable of executing code in a secure environment. For at least the processing of the "Secure Timestamp key" (as defined in FiRa standard) the UWB SoC needs to protect these assets in the security-module (TEE or SE).
Unit:	Yes/No
Type:	Boolean
Weight:	1
Trend in Literature:	This implementation is the recommended technique according to very recent literature, and particularly also included in recent FiRa consortium documents.
Test Environment:	Test by internal a) code-inspection and b) low-level debugging/logging the secured-communication between UWB and security parts is executed during the test.

7 Conclusion

7.1 Contribution to Overall Picture

The objective of INN2 is to develop ECS for Cognition and HMI which aims to improve overall user safety and increase the vehicle's interaction with the external environment.

The work depicted in the contents of this deliverable will be a starting point for most, if not all, the design and development work of the various technologies involved in the demonstrators of INN2 (and, to a lesser extent, those in INN1 and INN4), as they will have to attain to strict requirements which will be hopefully fulfilled, together with achieving the performance metrics set in the KPIs. After these phases, this deliverable's contribution will still remain relevant, as it will provide the metrics by which various tests will be performed in order to validate said advancements.

7.2 Relation to the state-of-the-art (SOTA) and progress beyond it

SOTA – IFAT

IFAT's Laser Beam Scanning activities addresses the following automotive applications, as highlighted in Figure 9:

- **AR HUD** enhances safety by providing driving information directly in the driver's line of sight.
- **Panorama HUD** reduces cognitive load by presenting critical information within the driver's natural field of vision.
- **Smart Surface** minimizes visual distraction by presenting HMI elements only when they are needed.
- **Dynamic Interior Projection (DIP)** enhances state of alertness or contrary reduces stress depending on the driving context.
- **Dynamic Ground Projection (DGP)** enhances safety of road users interacting with vehicles.

Although not in focus of ShapeFuture's activities, Laser Beam Scanning and MEMS mirrors are the prime enablers for automotive LiDARs [2]. However, the LiDAR market massively underperformed in the past and will not develop a similar dynamic like DGP or DIP applications [3]. Therefore, IFAT is not specifically regarding the LiDAR use-case in ShapeFuture.

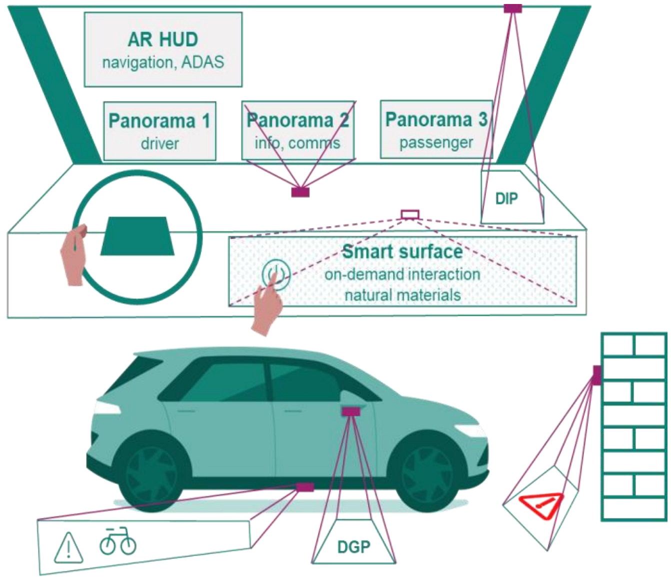


Figure 9: IFAT's addressed LBS applications

The fundamental enabling technologies for all these applications is IFAT's Compact Scanner Module which is being researched and developed within ShapeFuture. Apart from IFAT's Laser Beam Scanning, there are also competing technologies approaching this vast market. Competing display technologies such as Digital Light Processing (DLP) or Liquid Crystal Displays (LCD) either cause a high bill-of-material or are incompatible with the novel and emerging display optics that are required for AR and VR solutions. Therefore, DLP and LCD technologies do not qualify for a mass-market integration into automotive HUDs. Although available Laser Beam Scanning solutions of competitors are able to fill these crucial gaps, the state-of-the-art solutions lack in achievable display resolution and refresh rates. Laser Beam Scanning also surpasses other competing technologies in light efficiency (the higher the efficiency, the lower the power consumption) and capability for module-miniaturization (no bulky optical assemblies required). Furthermore, currently available automotive mirrors from competitors do not support mirror diameters of >1mm while achieving the required high resonance frequencies, which impairs the projection performance significantly. Table 2 summarizes the state-of-the-art technologies.

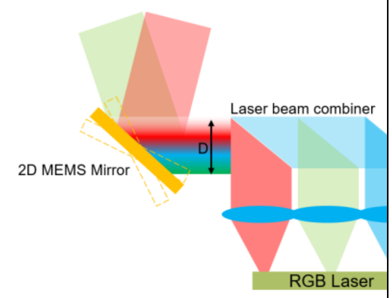
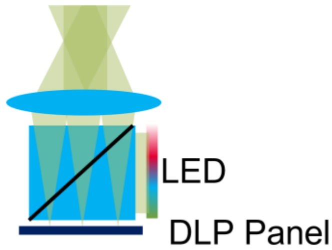
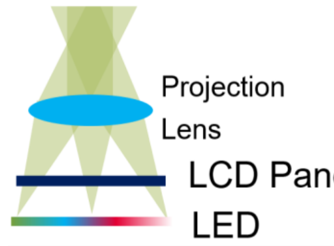
Tech	Laser Beam Scanning	DLP	LCD
			
Pros	• Low cost • ATV qualified with FuSa • Adequate image quality • Mature technology	• Mature technology • Adequate image quality • ATV qualified with FuSa support (new DLP chipset)	• Mature technology • Low cost • Adequate image quality • Accepted in FuSa–relevant systems
Cons	• Limited resolution	• High DLP chipset price (~100 USD) • Limited resolution	• Incompatible with novel display optics (size is too big)

Table 2: Display Technologies Pros&Cons

Some key performance indicators which will be addressed by IFAT's Laser Beam Scanning activities:

- Novel 2D MEMS mirror with 1.5mm diameter, enabling an optical field-of-view of at least 15° x 5° and a resolution of >100 pixels per degree.
- Novel MEMS Driver Electronics to control the 2D MEMS mirror with a jitter (pointing stability) of <1pixel.
- A compact scanner module dissipating less than 100mW.

SOTA – IMEC

The automotive industry is introducing various levels of autonomy into commercially available vehicles. These levels of autonomy need to substitute for a human driver in both sensing and decision making. The main task of the sensors is to provide the most reliable and dense information on the vehicular surroundings. The sensors need to detect, localize, and classify a variety of typical objects, such as vehicles, pedestrians, poles, and guardrails. Radars are robust to adverse weather conditions, are insensitive to lighting variations, provide long and accurate range measurements. Historically, automotive radars were classified into long range radars (LRRs), short-range radars (SRRs), and side-blind zone radars

(SBZAs). Autonomous driving requires high-resolution sensing capabilities, and thus automotive radars must provide high-resolution information on the vehicle environment in the range–Doppler–azimuth–elevation domains [4]. Range resolution is inversely proportional to the radar bandwidth. In 77-GHz radars, the available bandwidth is 4 GHz, which provides sufficient range resolution. Doppler resolution is limited by the coherent observation time and depends on the transmitted waveform, receiver processing, and target dynamics. Angular resolution is contingent upon the antenna aperture and thus is determined by the number and geometry of the transmit and receive channels, limited by the radar cost and packaging size. The requirements for high-angular resolution in both azimuth and elevation, using a small number of channels makes that the majority of state-of-the-art automotive radars use some variant of MIMO radar [5]:

Uhnder's [6], an Austin based startup founded in 2015, flagship product is the S80 which operates in the 76-81 GHz frequency range, and has a staggering 192 virtual receive channels using 12 transmit antennas and 2x8 receive antennas, of which 96 virtual receive antennas operate in true MIMO.

Texas Instruments (TI) is a dominant player in automotive radar. TI's latest automotive radar offering is the AWR2544 76-81 GHz FMCW radar-on-chip sensor that they unveiled in CES 2024. It uses four transmit and four receive antennas (seen in Figure 10) with a special Launch-on-Package (LOP) interface. LOP is essentially the inclusion of a 3D waveguide on the back side of the PCB with the radar chip, and reduces the overall size of the sensor by 30%.

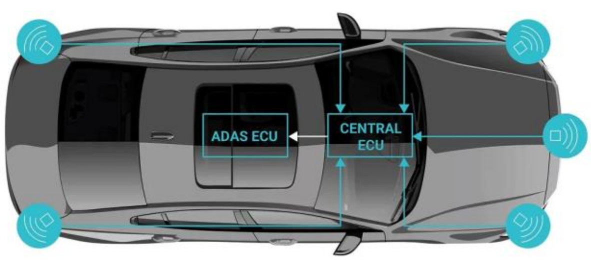


Figure 10: Image courtesy – TI

NXP released the SAF86xx 76-81 GHz automotive radar SoC in early 2024, with four receive and four transmit antennas, and built on 28nm RF-CMOS technology [6].

One of the major challenges in automotive radar is getting high angular resolution and that requires a large number of antenna elements in the MIMO array. Zendar [7] is a startup whose focus is on using Distributed Aperture Radar (DAR) to improve radar angular resolution without including a massive number of antennas on chip. A loose way of describing antenna aperture is simply how large the antenna is. The higher the aperture, the better the resolution of the antenna. Putting more antennas in an array does increase its aperture but it comes at the cost of having increased electronics to handle multiple channels. Zendar, working in collaboration with NXP, has a different approach which involves putting multiple radar sensor chips on a vehicle and operating them coherently so that they act like one bigger antenna, all of which can be seen in Figure 11.

Figure 11: Image courtesy – Zendar

SOTA – IFAG and IFAT

Car access systems have been around for decades, and have always been a target for hacking and theft. They have moved from physical keys over wireless keys to smartphone as a key application enabling more user convenience and safety. With the advent of Ultra-Wideband (UWB) technology, car access systems can now be made more secure than ever before. UWB is a wireless communication technology standardized by IEEE in the 802.15.4 domain. It is using an impulse radio (IR) principle for communication between two UWB transceivers. Ranging is performed by calculating the time-of-flight (ToF) of the signal which results in high accuracy (+/- 10cm) ranging of current UWB systems.

In recent years, various UWB-related standards have been defined and refined, such as the wireless-focused IEEE 802.15.4z standard [8] [9], in which defined improved security of UWB systems, or the more application-related FiRa consortium [10], in which also Infineon recently has joined. Particularly in the automotive context – in order to counter the security vulnerabilities of previous technologies which were attacked through relay attacks – the Car Connectivity Consortium (CCC) introduced a new standard [11] for car access using UWB as secure ranging technology for touchless car access. Parts of these standards are the underlying basis for the UWB chip hardware development (IFAG) and corresponding chip-firmware and embedded system-software developments (IFAT) for the secure-car-access Dem 2.3.

7.3 Next steps: Impact to other WPs, Tasks, and INNs

The next steps regarding Dem 2.1 and the Compact MEMS Scanner module are defined as follows. IFAT sped up the development activities as much as possible. While the system level design (WP2, task 2.2) was finished during the first 12 months of the project, development of the required component (WP3, task 3.2) started at full steam. IFAT aims for the LBS demonstrator an iterative development process. Components which are available right now are being integrated (WP5, task 5.2) and will be exchanged with their newest versions as soon as they are available.

By doing so, an early demonstration (WP6, task 6.2) will be secured leading to a successful ShapeFuture project execution.

As for Dem2.2, taking the requirements within T1.2, the focus in T2.2 is on the exploration of coherent and non-coherent processing of both bistatic as well as monostatic radar data. This will result in an optimized radar node placement and accompanying algorithms. The specifications for the radar nodes resulting from T2.2 will be used in T3.2 to design the radar nodes as well as the central node that generates the FMCW chirp and processes the data coming from the distributed radar nodes. An important aspect in the design is the distribution of the FMCW chirp. The complete demonstrator will be integrated together with radar processing in T5.2 and finally evaluated in the lab within T6.2.

In the next steps for Dem 2.3, the requirements presented herein will be first and foremost considered in the UWB SoC-design phase carried-out by IFAG within T2.2, and in the corresponding combined UWB- and security- system-concepts defined by IFAT within T2.2. Then, the specific hardware-related requirements (such microcontroller features or power-consumption) will be used and considered by IFAG within T3.2 for their SoC developments. The other higher-level UWB system-integration and security-related requirements will be tackled by IFAT within T5.2. Finally, the achievement of the Dem 2.3 requirements and KPIs defined herein will finally be evaluated by IFAG and IFAT within T6.2.

Similar considerations will take place for Dem1.4 and Dem4.3, where these requirements will lead to the development of the various cognition (as in the case of the augmented SA in driving) and HMI (excavator tele-operation) components which will take part in the demonstrators.

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