

Contract N. 295364

DESERVE

Development Platform for Safe and Efficient Drive

[DESERVE Inter-Urban Assist – Platform requirements and specification]

Deliverable n.	D46.1 – Platform requirements and specification for inter-urban assist		
Sub Project	SP 4	[DESERVE Platform]	
Work package	WP 46	[Inter-urban assist]	
Task n.	T 4.6.1	[Deserve platform requirement engineering for inter urban assist]	
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Status	Final		
Distribution	Restricted Partners (RP)		
Issue date	25.09.2013	*Creation date*	2013/08/08
Project start and duration	1st of September, 2012 – 36 months		

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LIST OF ABBREVIATIONS

ABBREVIATION	*DESCRIPTION*
ADASIS	Advanced Driver Assistance System Interface Specification
DoW	Description of Work
WP	Work Package
IUA	Inter-Urban Assist
DAS	Driver Assistance System

REVISION CHART AND HISTORY LOG

REV	*DATE*	*AUTHOR*	*REASON*
0.1	08.08.2013	Werner Ritter	Initial document
0.2	14.08.2013	Roland Schweiger	Daimler contributions
0.3	16.08.2013	Martin Kunert	Bosch contributions
0.4	16.08.2013	Matthias Limmer Oliver Hartmann Nora von Egloffstein	Daimler contributions
0.5	01.09.2013	Holger Blume/ Guillermo Paya-Vaya	IMS contributions
0.6	03.09.2013	Werner Ritter Nora von Egloffstein	Daimler contributions
0.7	11.09.2013	Werner Ritter Martin Kunert	Version for peer review
1.0	24.09.2013	Werner Ritter Nora von Egloffstein	Last corrections after peer review. Final version.

EXECUTIVE SUMMARY

In this document the Inter-Urban Assist is described as an automotive application test case for the validation and proof of concept of the general DESERVE development platform for embedded systems.

The Inter-Urban Assist is a driver assistant system of the next generation, offering vision support while driving on rural roads, especially during night drives. Vision support is realized in three different functionalities. The Inter-Urban Assist offers driver support by an augmented visualization of the scene ahead of the driver, a perfect illumination of the scene ahead and with a warning spotlight function.

As the idea of the DESERVE platform is to speed up the development process by reusing basic system modules, the Inter-Urban Assist is built upon an architecture of interconnected modules in the perception layer processing data from the perception input sources.

In order to realize the support functionalities of the Inter-Urban Assist, cameras, radar, digital map and vehicle data are specified as necessary perception input sources.

Four different modules are processing data from the perception input sources while also forming a network between each other. Self-Calibration, 3D Reconstruction, Lane Course and Scene Labeling were identified as these four main perception platform modules for the Inter-Urban Assist demonstrator.

The content of this document is the first edition that will serve as a basis for further development in subsequent reports or deliverables. Especially the methods and algorithms in the perception modules are subject to further development in the course of the DESERVE project.

1. INTRODUCTION

1.1. Objectives and scope of the document

In this report the DESERVE platform components necessary for the implementation of the functionalities of the Inter-Urban Assist (IUA) are defined and specified. The architecture and the information flow between the different subsystems are specified. This serves as a basis for an identification of possible bottlenecks. The partitioning of the subsystems' workload in embedded realizations (i.e. hardware accelerators) and new functionalities that are running in the rapid prototyping domain are determined by using the proposed model-based design space exploration introduced in Deliverable D2.1.3 – Development Methods [REF2].

The whole process chain will be focused on video-based systems that have the highest demands in calculation power.

For a successful realization of the Inter-Urban Assist in the DESERVE platform, the whole application needs to be analysed and structured at different levels.

The necessary granularity, architecture and inter-connectivity will be established in several iteration cycles to achieve the optimum configuration.

1.2. Structure of the deliverable

This report is structured as follows:

Chapter 1 provides the objectives and scope of this document as well as an introduction to the general concept of the Inter-Urban Assist demonstrator.

Chapter 2 represents the main part of this document. First, the functionalities of the Inter-Urban Assist are described. Next, the module architecture and the information flow of the Inter-Urban Assist are specified. They form the basis for a detailed description of the modules of the Inter-Urban Assist.

Chapter 2 closes with a first draft of the hardware and software requirements to realize the IUA.

Chapter 3 concludes on the document and gives an outlook for next steps.

1.3. General concept of the Inter-Urban Assist

The objective of Work package (WP) 46 is to test and validate the general DESERVE embedded system concept with a complex automotive application of the next generation driver assist functions, the Inter-Urban Assist. As the idea of the DESERVE platform concept is to speed up the development process for new Driver Assistance Systems (DAS) significantly by reusing a significant number of well tested basic system modules for next generation implementations, a granular subdivision of the Inter-Urban Assist in the perception layer is necessary.

The IUA offers different driver supporting functionalities build upon a module architecture consisting of four interconnected modules. These modules build a sub-layer between perception sources and the actual application.

In order to prepare the IUA for the integration in the DESERVE development process, the requirements of the modules have to be identified and specified. Requirements means in this context identifying the demanded input sources, the methods used in the perception modules as well as the interconnection between the modules.

In the following chapter the functionalities and requirements of the IUA will be described and specified as well as their requirements on the underlying platform.

2. THE INTER-URBAN ASSIST

2.1. Functionality of the Inter-Urban Assist

The test function for the usability and proof of concept of the DESERVE platform is the IUA. The main objective of the IUA is to assist the driver while driving on connection roads (highways, country roads, rural roads) between cities, especially during night drives. The IUA is a DAS supporting the driver mainly by vision enhancement.

Vision support in this context can be established in different ways.

When driving on a narrow or curvy rural road, the further course of the road is often difficult to perceive. Additionally, obstacles are often not recognized in time, especially during darkness. Thus, the IUA supports the driver by offering an enhanced visualization of the road scene in front of the car.

During driving on roads with a high level of cornering, the IUA supports the driver with a perfect illumination of the road ahead of the car. Thus, the driver is guided by a light functionality that is predicting the lane course by swivelling the main beam in the forward road heading.

As vulnerable road users are often not recognized in time by the driver, the IUA incorporates a spotlight functionality as a warning system to attract both the driver's and the vulnerable road user's attention.

In summary, the IUA comprises the following functionalities:

- An augmented night vision system, where the road and the obstacles in the scene ahead of the car are marked in the presented (night view) display so that they could be perceived immediately.
- A predictive front light for a perfect illumination based on the predicted road course ahead of the car
- A spotlight functionality as intuitive warning system for vulnerable road users like pedestrians

Figure 1 – A possible augmentation of night vision imagery

2.2. Module Architecture of the Inter-Urban Assist

The display or lighting control functionalities of the IUA are established by an interoperability of the perception modules gathering information from the perception sources. In the following subsection the choice of the input sources, as listed in D1.2.1 – Development Platform Requirements [REF1], are motivated.

In order to support the driver with an augmented image of the scene ahead, images of a camera are necessary as input source of the IUA. Since the images are meant to be shown to the driver, a frame rate of at least 25 frames per second is needed. Towards augmenting an image with 3D information, the range of possible 3D reconstruction is limited by the resolution of the images, among others. The driver should be made aware of critical objects ahead of the car. With an appropriate aperture angle this could be achieved with a video imager resolution of at least 1024x512 pixels. Since image processing methods for 3D reconstruction are more promising at higher pixel bit depths, the requirement of at least 10 bits of intensity resolution is formulated. In order to estimate the position of moving objects in the scene, a synchronous exposure of the cameras is absolutely necessary.

In order to complete the exploration of the scene ahead of the driver, especially while driving at higher speeds, radar is chosen as an orthogonal sensor w.r.t. to the image sensor. In order to reconstruct the environment as accurate as possible, raw radar data is needed, in format of a peak list per radar range cell.

To enable the predictive light functionality of the IUA, a digital map is essential. As lane markings offer a road prediction only up to 40 meters in front of the vehicle, only a digital map can offer the desired localization and prediction accuracy. The digital map should be available in Advanced Driver Assistant System Interface Specification (ADASIS) format, just as in other standard automotive applications.

As vehicle odometry is a basic input source for driver assistant systems, all existing on-board vehicle information is identified as the fourth perception input source.

The four perception input sources are also summarized in Table 1 – Perception module input sources.

Front cameras	• Used for visualization functionality and further processing • Grey level images, sufficient bit depth and resolution • Simultaneous exposure

Radar	• Sensor orthogonal to image sensor • High range necessary while driving on rural roads at high speed • Raw radar data, not only data of preceding vehicles
Digital Map	• Digital Map Data and position data essential for predictive light functionality • ADAS-accuracy, ADASIS-interface
Vehicle Data	• Vehicle odometry based on on-board sensors (yaw rate, wheel ticks, accelerations, suspension level sensors, …)

Table 1 – Perception module input sources

To realize the functionalities of the IUA, the perception input sources are further processed in four perception modules. These perception modules are Lane Course, Scene Labeling, 3D Reconstruction and Self-Calibration.

The complete module architecture of the IUA is illustrated in Figure 2 - Module architecture and signal flow of the IUA and described in the following.

The desired application scenario for the IUA is supporting the driver on curvy rural roads during night drives with oncoming traffic, a great variety of traffic participants (such as trucks, cars, motorcycles, bicycles, pedestrians) and for speeds up to 100 km/h (in Germany). Thus, the driver should be made aware of road course and objects up to a few hundred meters ahead of the car. To deduce 3D information from 2D images for such long ranges, a rather large baseline for a stereo camera system is needed. As such a wide-baseline camera system cannot be realized like a common stereo camera system with a rather small baseline, the cameras are mounted individually at the vehicle. To ensure correct 3D information, accurate knowledge about the camera parameters is needed. A one-time offline calibration does not meet the accuracy requirements for such a non-rigidly coupled camera system. The camera system needs to be constantly recalibrated during driving, which inhibits using know calibration targets such as checkerboards.

Consequently, there is a Self-Calibration module in the perception layer.

To support the driver with a video augmented with information about the scene ahead, 3D information about the image scene is needed. This is carried out in the 3D Reconstruction module, given 2D images and the camera parameters.

To enrich 3D information by semantic information of the 2D image, each image pixel needs to be assigned to an object class, i.e. ‘road’, ‘vehicle’, ‘pedestrian’, ‘background’ and so on. This is achieved in the Scene Labeling module.

The predictive light functionality offers the driver a perfect illumination of the road. This functionality relies on an estimation of the course of the road ahead of the driver up to a meaningful distance. Lane course estimation is the task of the Lane Course module.

All the perception modules are summarized in Table 2 – Perception modules.

Lane Course	• determines the trajectory of the lane in front of the car up to a meaningful distance ➔ used for predictive light functionality and augmented night visualization
Scene Labeling	• estimates class membership values for each pixel ➔ used as semantic information about the scene
3D reconstruction	• estimates the spatial structure of the scene in front of the car ➔ offers 3D information corresponding to 2D image pixel
Self-Calibration	• estimates the calibration information for each image pair ➔ required for 3D information estimation

Table 2 – Perception modules

2.3. Information flow in the Inter-Urban Assist platform

The perception modules of the IUA are organized in an interconnected architecture.

As shown in Table 2 – Perception modules, the perception modules require not only external perception input sources but an information flow between themselves.

The information flow between the Self-Calibration module and the 3D Reconstruction module is established in both directions. In order to estimate the spatial structure of the scene in front of the vehicle, accurate knowledge about the camera parameters is necessary. This information is offered by the Self-Calibration module.

The 3D information of an image point estimated by the 3D Reconstruction module is redirected into the Self-Calibration module. The calibration information from the Self-Calibration module serves also as input for itself in a feedback loop.

The Scene Labeling module is favoured by additional scene information provided by the estimated trajectory of the Lane Course module and spatial information of the scene ahead as output of the 3D Reconstruction module.

Similarly, scene information offered as 3D information of the 3D Reconstruction module or the classified pixel image given by the Scene Labeling module is useful for further processing in the Lane Course module.

Finally, the interconnected architecture of the IUA enables a consistent and reliable estimation of the road scenery ahead.

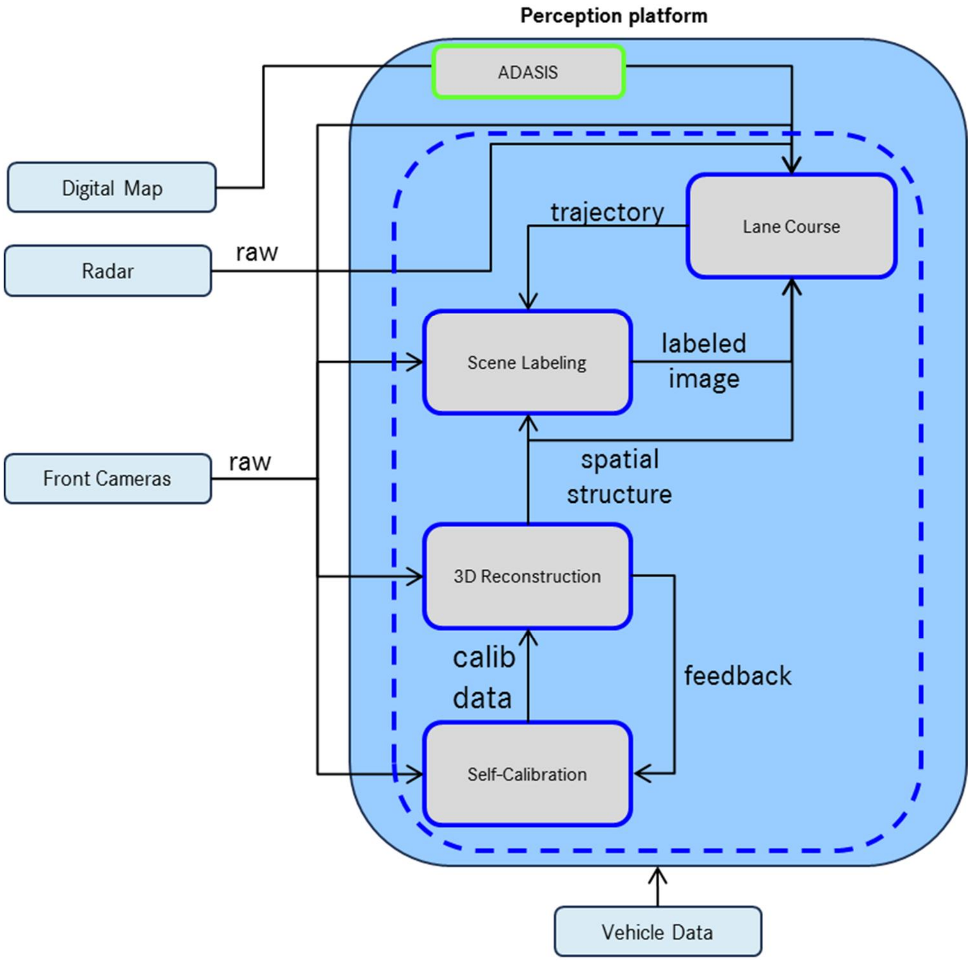

Figure 2 - Module architecture and signal flow of the IUA

2.4. Module Specification 'Self calibration'

The Self-Calibration module of the IUA estimates the calibration information of an image pair in order to estimate correct 3D information in the 3D Reconstruction module. Calibration information comprises the extrinsic parameters of a camera system as well as intrinsic parameters of each single camera.

2.4.1. Input

- Vehicle odometry based on on-board sensors

- Two front camera images

2.4.2. Output

- Camera calibration information for the current image pair
    - intrinsic camera parameters, e.g. camera constant, distortion parameters for each camera
    - extrinsic camera parameters, i.e. transformation between the two camera coordinate systems

2.4.3. Methods

Self-Calibration covers estimation of the camera parameters while driving, given at least two images of the same scene.

Relying only on 2D image data, the objective of a Self-calibration method is to estimate the extrinsic and intrinsic parameters of the camera system causing these images.

Thus, self-calibration incorporates identifying image points of the same 3D point in both images respectively. As image measurements are often distorted due to noise, Self-Calibration methods have to account for outlier or noisy measurements.

2.5. Module Specification '3D Reconstruction'

The 3D Reconstruction module estimates the spatial structure of the scene in front of the car.

2.5.1. Input

- Vehicle odometry
- Two front camera images
- Current calibration information from Self-Calibration module

2.5.2. Output

The module 3D Reconstruction delivers 3D information about the scene ahead of the car. The 3D information is organized in a 3D point cloud, where a 3D position per point is available.

2.5.3. Methods

3D Reconstruction covers the estimation of the 3D positions of the points shown in the video images. Corresponding to their position in the images and the information about camera's position, orientation and intrinsic parameters, the 3D Reconstruction module deduces the 3D position of image points.

2.6. Module Specification 'Lane Course'

The Lane Course module presents an advanced road course prediction focusing on longer distances.

2.6.1. Input

- Vehicle odometry based on on-board sensors (yaw rate, wheel speed, accelerations, coarse GPS coordinates etc.)
- Road geometry based on a digital map provided via the ADASIS protocol.
- A long range radar sensor
- A camera image providing a label of the visible road course

2.6.2. Output

- The road course geometry in front of the vehicle.

2.6.3. Methods

In order to determine an accurate estimation of position and orientation, the digital map is matched with a local environment map that is constructed by integrating the radar sensor data with the help of vehicle odometry information. Furthermore, the road course prediction given by the camera image is fused with the digital map to improve the estimation for short ranges.

2.7. Module Specification 'Scene Labeling'

The Scene Labeling module of the IUA estimates a class membership for each pixel of an input image in order to conduct a semantic segmentation of that image. The scene labelled image is used in the Lane Course module. To leverage the quality of the scene labels, a feedback trajectory from the Lane Course module as well as the spatial structure of the 3D Reconstruction module is used.

2.7.1. Input

- Trajectory of the Lane Course module
- Spatial structure of the 3D-Reconstruction module
- Front camera images

2.7.2. Output

- Scene labeled images

2.7.3. Methods

Scene Labeling estimates a class membership for each pixel of a given image.

This process is divided into feature extraction with a predefined feature extractor and a label estimator that uses the extracted features to associate the most likely label.

The labeling is temporarily and spatially smoothed to reduce noise and flickering.

2.8. General demonstrator hardware requirements

For the Inter-Urban Assist demonstrator a specific DESERVE platform will be implemented as a prototype using EB Assist ADTF in combination with the dSPACE MicroAutoBox II.

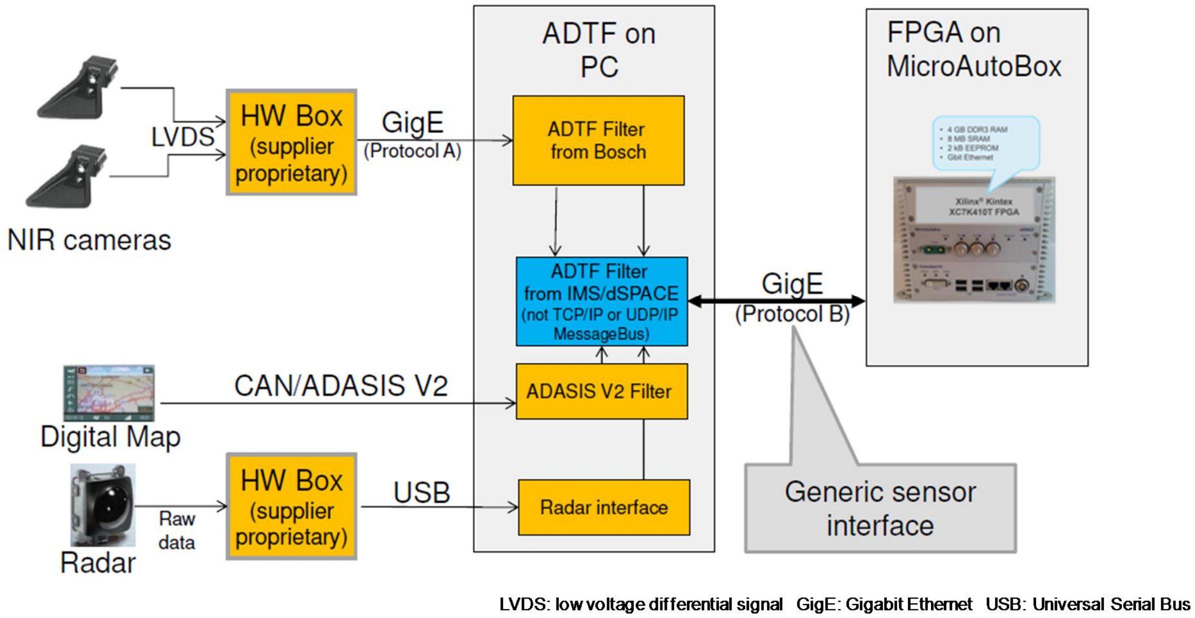

Figure 3 - Block diagram of the Inter-Urban Assist demonstrator

A first release of an FPGA-based hardware prototype of the Inter-Urban Assist demonstrator was implemented and will be used to develop and verify the signal processing building blocks. This first release, described in Deliverable D2.1.3 – Development Method (First release) [REF2], is based on a Xilinx FPGA Board ML605 evaluation board. Later, the implemented signal processing blocks will be used within the dSPACE MicroAutoBox II for the final release of the Inter-Urban Assist demonstrator (see Figure 3 - Block diagram of the Inter-Urban Assist demonstrator).

The ML605 Xilinx Evaluation FPGA Board includes a Virtex-6 LX240T FPGA with enough calculation power to map several signal processing blocks for verification and demonstration purpose. Moreover, this evaluation board provides high speed connectivity by means of a Gigabit Ethernet or a PCI Express connection. Finally, this board supports up to 2 GB DDR-3 SDRAM memory that is available for video processing applications.

An overview of the hardware components to be used for the IUA platform is given in Annex 4.2.

2.9. General demonstrator tools and software requirements

Using the FPGA-based hardware emulation system

The FPGA-based hardware emulation system is implemented based on a flexible, modular and expansible framework. Two parts (i.e. tools) can be identified:

1) A software communication driver is used for connecting the software, which is running on a host PC, with the different signal processing blocks implemented on the Virtex-6 FPGA located in the ML605 board or with the DDR-3 SDRAM memory also located in the ML605 board. This connection uses the Gigabit Ethernet link and a hardware module mapped on the Virtex-6, which implements a custom MAC layer.
2) A flexible and modular bus infrastructure is used as a template for any FPGA hardware design. This template can be expanded with new signal processing blocks by connecting these blocks to the bus. For that, slave and master template hardware modules are also available in the framework.

The software communication driver can be used in the EB Assist ADTF or RTMaps framework as shown in Figure 3 - Block diagram of the Inter-Urban Assist demonstrator.

Using the model-based design space exploration approach

Identifying the best software/hardware realization of a system can be performed by an iterative process, described in Deliverable D2.1.3 – Development Method (First release) [REF2]. The application designer selects algorithms and defines their parameters. The evaluation of a hardware mapping of these algorithms indicates whether the hardware meets the requirements (i.e., achieving a desired processing performance or meeting some hardware resource constraints) or not and may lead to new insights or hints to the application designer that describe how the application parameters might be modified in order to allow a better hardware realization.

The proposed model based cost evaluation supports the system designer by allowing an exploration of the prevailing design space without the need for deep knowledge of the hardware technologies. Thus, the system can be analysed in early design stages and the feature estimates provided by the cost models can be used to drive the design process.

The design space exploration framework is built on quantitative cost models that describe different possible hardware implementations of application building blocks. The cost models are collected in a model library. For each application building block the model library contains a family of cost functions that describes the realization of that building block on a specific hardware technology. The cost functions in a family describe different characteristics of the specific hardware realization of the building block. These characteristics include performance (latency), power consumption, and silicon area. However, the model library is flexible and allows the integration of cost functions for additional characteristics, e.g., implementation cost, flexibility, throughput rate, etc. The evaluation tool will use all the available cost functions for evaluation of a basic block.

3. CONCLUSIONS

For a successful integration of the Inter-Urban Assist as the test function for the usability and proof of concept of the DESERVE platform a subdivision of the architecture is needed in order to achieve a highly detailed definition and specification of these modules and their requirements.

In this document a first edition of such a subdivision of the interconnected module architecture of the IUA based on its functionalities is provided. The comprising functionalities of the IUA are introduced as an augmented night vision system, a predictive front light and a spotlight functionality.

The perception sources enabling these functionalities of the IUA are identified and the necessary input sources are specified, mainly two front cameras, a long range radar, digital map and on-board vehicle data.

The functionalities of the IUA are established by an interconnected architecture of perception modules gathering information from the above mentioned perception sources. The IUA-intrinsic perception modules are Self calibration, 3D reconstruction, Lane Course and Scene Labeling. These perception modules of the IUA are organized in a mutually connected architecture. The information flow between input sources and perception modules has been described and specified.

Finally, first steps towards the implementation of the IUA on the DESERVE platform have been performed. Based on the specification of the IUA, general demonstrator hardware requirements, general demonstrator tools and software requirements for the implementation have been identified. Target hardware for the implementation of the IUA (and other functions) has been selected and first software implementation of tools and modules have been started on a first prototype system.

This document serves as a general basis for further development in order to realize the integration of the IUA in the DESERVE development platform.

Next steps will be further detailed specification of the perception modules and requirements of the perception input sources. Both data formats and algorithms will be further developed and implemented in the coming months.

4. ANNEXES

4.1. References

[REF1] DESERVE Deliverable D1.1.2 – Platform Needs

[REF2] DESERVE Deliverable D2.1.3 – Development Method (First release)

4.2. *Inter-urban Assist hardware components*

4.2.1. The IUA sensors hardware overview

In *Figure 4* the two video-cameras and the long range radar sensor that are used in the IUA demonstrator car are shown.

Figure 4 – Video and radar sensors used in the Inter-urban assist platform

4.2.2. The IUA embedded system component overview

In *Figure 5* the embedded system components used in the IUA platform are depicted.

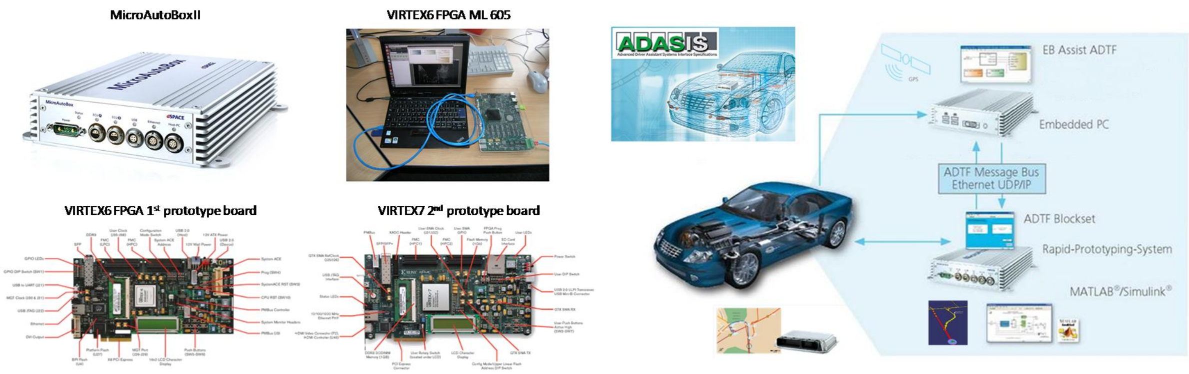

Figure 5 – Video and radar sensors used in the Inter-urban assist platform