D2.3

Overall system requirements

Dissemination level PU

Version 1.0 Final

Lead contractor ADS

Due date 31.10.2016

Version date 25.04.2017

Bundesministerium für Bildung und Forschung
Tekes
VINNOVA
Netherlands Enterprise Agency
ECSEL Joint Undertaking
Electronic Components and Systems for European Leadership
FLANDERS INNOVATION & ENTREPRENEURSHIP
Flanders State of the Art
Co-funded by the European Union

Document information

AUTHORS

Jan - Erik Källhammer - Autoliv Development AB (ADS)

Anders Cassel - Autoliv Sverige AB (ALS)

Werner Ritter - Daimler AG (DAI)

Armin Hürland - Daimler AG (DAI)

Nils Appenrodt - Daimler AG (DAI)

Hervé Illy - Renault (REN)

Laurens Hobert - Hitachi (HIT)

FUNDING

H2020-ECSEL-2015-1-RIA

Grant Agreement number: 692449

CONTACT

Dr. Werner Ritter
Daimler AG
Wilhelm-Runge-Straße 12
89082 Ulm
Germany

Phone: +49 731 505 2140

Email: Werner.R.Ritter@Daimler.com

www.DENSE247.eu

LEGAL DISCLAIMER

Revision log

Version	Date	Reason	Author	Company
0.5	09.11.2016	D: draft	JEK	ADS
0.6	20.12.16	Add text Vehicle integration and packaging	WR+AH	DAI
0.10	22.01.17	Add text in Interfaces with communication system and Requirements for calibration	HI	REN
0.11	27.01.17	Review	HI	REN
0.12	27.01.17	Corrections and add text for radar	NA	DAI
0.17	7.2.17	Final draft	JEK	ADS
0.18	13.02.17	Final draft 2	JEK+TM	ADS/EICT
0.19	16.02.17	Review	WR	DAI
0.20	17.02.17	Road friction sensor update	MK	VTT
0.21	27.02.17	Addressing review issues	JEK	ADS
0.22	28.02.17	Correcting table references, update road state sensor spec	JEK	ADS
0.23	04.04.17	Revision and inclusion of updates	TM	EICT
0.9	25.04.17	Final Review Project Coordinator	WR	DAI
1.0	25.04.17	Final formatting	BH	EICT

Table of contents

List of figures

List of tables

1 Summary

The present document, Deliverable D2.3, provides the overall system requirements and describes the functional requirements of an all-weather perception sensor suite in order to support the use case scenarios described in Deliverable *D2.2 – System needs and benchmarking*. [1] The document also takes into account the inputs from the analysis described in Deliverable *D2.1 Characteristics of Adverse Weather Conditions*. [2]

The DENSE system aims to overcome the problem of limited perception capability in restricted visibility conditions. The concept boosts performance by merging elements of three different sensor types: (i) Infrared camera sensor (ii) Lidar and (iii) radar. The additional inclusion of Road friction sensing will allow assessment of road surface conditions. The information of these sensors is then combined via a Convolutional Neural Networks (CNN) to efficiently fuse information from the various sensors.

The aim of the DENSE project to achieve higher detection ability in adverse weather rests on the ability of the (CNN) to extract useful information from several sensors even if their outputs are degraded due to the adverse weather conditions. Having more than two sensors also means that a level of robustness and fault tolerance can be achieved even if data from one sensor is lost due to faults, obstructions, or other reasons. However, that also means that an ultimate system will need to have overlapping sensing areas for the involved sensors.

For timing and financial reasons, the sensors in the prototype installation will not comply with the ultimate specifications in all aspects, but will be selected to achieve a reasonable system demonstrator to prove the viability of the sensor suite in combination with the CNN to achieve the increased performance in adverse weather conditions. The present document aims to specify the requirements of the ultimate targeted system, when relevant for the ultimate system, and specify the requirements restricted to the demonstrator for aspects not fundamental to the scope of DENSE. The implemented demonstrator will therefore have some limitations mainly on system field of view and some system aspects such as ultimate user interface and vehicle integration in a targeted vehicle which will be referred to the serial development phase.

The short wave infrared (SWIR) sensor is an optical sensor which offers resolution and multi-purpose abilities in a similar fashion as visual cameras do, but with better range when the atmosphere contains obscurants such as rain, fog and snow due to the longer wavelength. However, conventional continuous illumination offers limited benefits due to the back-scatter from the obscurants in the atmosphere (compare with driving with high-beam in fog). Adding pulsed illuminations and gated cameras allow for filtering away any backscatter which is outside the range of interest. The camera will only receive light at short, specific times coupled to the return of the short illumination pulses. By combining several of such image slices we can build a complete image eliminating most of the blinding effect otherwise caused by the backscatter.

LIDAR utilizes a similar principle, but here the pulses are even shorter and usually only discrete points in the scene are illuminated. By measuring the time for the light pulse to return, a precise distance map in the direction of the emitted light pulses is generated.

Radar is an excellent sensor for accurately measuring distances and also generates an accurate velocity reading of the detected object due to the Doppler Effect. The longer wavelengths (~5000 times longer than visible light) generate better penetration in an atmosphere with obscurants. However, radar's lack of lateral resolution implies limitations in the ability to accurately ***recognize*** which type of objects have been ***detected***. We will explore a new type of radar utilizing multiple input and multiple output (MIMO) to enable higher lateral resolution.

The overall system requirements are based on the use cases documented in Deliverable 2.2. System needs and benchmarking. [1] Deliverable 2.2 investigated use cases and weather-accident scenarios relevant for an all-weather assistance system. There were five use cases defined. Two of the use cases mainly determine sensor requirements, another two use cases mainly determine decision abilities, while the fifth use case targets the stand-alone road state estimator. The joint requirements derived from all use cases will determine the full sensor and classification abilities of the sensor suite to be developed. The results of that analysis were then used to define functional requirements in the present document, which is summarized in Table 5.1. The overall vehicle integration constraints are described. The integration aspects in the vehicle are covered, especially the packaging considerations of the three main types of sensors used –RADAR, LIDAR and cameras. For each of these sensor types, individual factors for the integration are presented. The boundaries of the demonstrator's sensor suite and its integration in the vehicle's communication system are described. The functional safety level verifications needed of the fusion platform and its sensors and interfaces are outlined.

2 Introduction

Work Package 2 is the starting point and framework for the whole work as it defines the functional requirements of the integrated sensor system, scenarios and benchmarks as well as adverse weather conditions. The insights on adverse weather conditions are essential for the overall goal of the project, the development of the integrated sensor system and the impact assessment of the system in its dimensions of safety and user support. Consequently, the defined requirements as well as benchmark and scenario definitions are the basis for the later work in WP3 on specifications of the DENSE system which also constitute the framework for WP6 on evaluation.

2.1 Task 2.3 Requirements

The focus is on the overall and functional requirements of the DENSE integrated system to serve the specifications and development phases based on previously defined system needs in Task 2.2.

The work defines functional requirements for a system aiding the driver in adverse or inclement weather such as rain, fog, and snow. The requirements form the basis to define detailed system and subsystem specifications in WP3 and for the system evaluation. The focus in Task 2.3 is on the requirements of the ultimate targeted system when relevant for the scope of a DENSE system, and on specifying the requirements restricted to the demonstrator for aspects not fundamental to the scope of DENSE. The implemented demonstrator will therefore have some limitations mainly on system field of view, and some system aspects such as ultimate user interface and vehicle integration in a targeted vehicle which will be referred to the serial development phase.

3 Methodology

The use cases were analysed with respect to the sensory requirements and an assessment based on previous experience of how many data points will be required in the outcome of the final CNN fusion process.

There are five use cases defined in Deliverable D2.2. [1] These are:

1. Stationary object on the road (road debris)
2. Traffic jam ahead
3. Pedestrian crosses the road
4. Enhanced environmental awareness
5. Drivable Area Awareness

3.1 Use case 1: Stationary object on the road (road debris)

This use case tests the detection limits of the sensor system. Driving over road debris such as a broken tire would likely damage the vehicle. Normal clearance in the front facia is about 10 cm. A common 185/55 R15 tire is 185 mm high, when resting flat on the ground. Low profile tires and truck tires are wider (taller when resting flat on the road). Use case 1 defines resolution requirements in the forward driving direction. Resolution has to be higher than the detection limit, as detection is not enough to initiate a vehicle response – the object has to be recognized with reasonable confidence. Naturally, more points on the object will improve the recognition reliability. The selected level of number of points at the height of a tire is based on experiences from related applications and is considered at a lower limit of what is acceptable.

3.2 Use case 2: Traffic jam ahead

This use case tests especially the recognition ability of the system with and without degraded sensor data, thus the performance of the CNN. The DENSE system needs to recognize the situation sufficiently far ahead to come safely to a stop before the last vehicle of the stopped traffic. Collisions with stationary vehicles often cause extremely serious collisions with high damage and serious injuries or even deaths. Object classification of stationary vehicles is a challenging problem to solve for systems solely relying on radar. Use case 2 defines the required ability of the CNN fusion system to reliably recognize vehicles (traffic jam) ahead, dealing with potential disturbances such as reflections and multipath signals from infrastructure.

3.3 Use case 3: Pedestrian crosses the road

This use case tests both the detection limits of the sensor system with high lateral angles and the system's recognition ability when radar data is uncertain. In addition, many pedestrians do not wear any reflective markers or otherwise use garments to increase their visibility. Clothing with low reflectivity must therefore be considered.

3.4 Use case 4: Enhanced environmental awareness

This use case tests the ability to estimate road friction in front of the vehicle. Reduced road friction implies significant higher risk of crashes, both during winter time as well in rain due to aquaplaning. The transition between autumn and winter can be especially difficult with the presence of black ice. Melting snow and ice may falsely give impression of a wet road with good friction, but having a layer of ice beneath the water. A friction estimate can be done if the road conditions can be estimated accurately enough. This assessment will provide the driver or the automated system a state of the road conditions. In addition to the friction estimation, the system is intended to provide information concerning other objects (material) in front of the vehicle to minimize the number different sensors.

3.5 Use case 5: Drivable Area Awareness

This use case tests the ability of the system to estimate free space in front of the vehicle with and without degraded sensor data. Free space estimation is a fundamental function for automated driving operation. This function becomes more important under adverse weather condition where it is important to identify possible free space for evasion manoeuvres. Use case 5 defines the required ability of the CNN fusion system to reliably recognize free space ahead, dealing with potential disturbances such as reflections and multipath signals from infrastructure.

3.6 Deriving requirements

The above listed use cases were analysed for their impact on either the sensor requirements or the fusion system's classification requirements. Use case 1 and 3 mainly determine sensor requirements, while use case 2 and 5 mainly determine classification abilities. Use case 4 targets the stand-alone road state estimator. The joint requirements derived from all use cases will determine the full abilities of the system to be developed.

4 System needs and overview

The degraded information from the sensor affected by the adverse road conditions have to be enhanced and fused together to jointly produce a view of the scene in front of the vehicle that is better than what can be achieved with each individual sensor. A reconstructed description of the road and environment ahead is ultimately the target from which decisions can be made by the control system (outside the scope of this project).

4.1 System overview

A specialized artificial neural network architecture will be developed tailored to process all-weather sensory information. A conventional model of a Convolutional Neural Network will be extended to benefit from sparse information processing paradigms. This enables the representation of highly nonlinear transformations without the need for a disproportionate number of neural building blocks. The integration of multi-scale representations provides valuable input for scene understanding and object detection. Identification of spatial redundancies allows for more robust modelling of contextual information, such as a car on the road. Feedbacks can be provided to the sensor suite in order to enhance the data acquisition or even focus on a particular area. The conceptual system hierarchy is depicted in Figure 4.1.

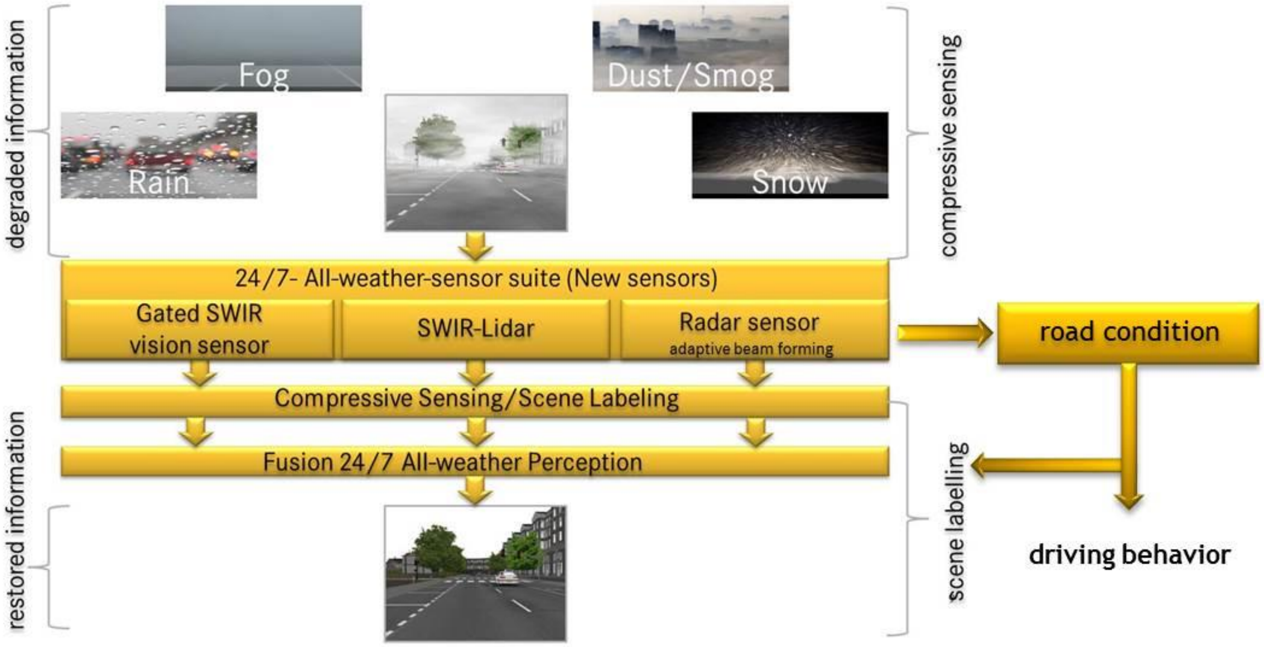

Figure 4.1: DENSE system architecture of the 24/7 all-weather-sensor suite.

5 System requirements

From the use cases described above two categories of requirements can be determined:

- Requirements of the sensor
- Requirements of the fusion system processing the sensory data.

The focus of the processing fusion system is to utilize the degraded sensory data during adverse weather conditions and still manage to perform a sufficiently accurate classification of objects and free space around the vehicle. This also means that minimum sensor specifications are based on minimum ability in fair weather conditions when no degradation of sensor signal will occur due to weather related factors. Thus minimum sensor performance need to allow detection of defined use cases at a minimum distance and direction to the targeted object, without the influence of degraded visibility conditions. The minimum sensor requirements are hence based on the use cases in fair weather.

The focus of this specification is on the requirements of the ultimate targeted system when relevant for the ultimate system, and on specifying the requirements restricted to the demonstrator for aspects not fundamental to the scope of DENSE. Sensor requirements are therefore described as the requirements of the targeted system, although timing and budgetary restrictions imply that the demonstrator will not fulfil all these targets, an example being a narrower field of view.

The requirements derived from the use cases described in D2.2 [1] are summarized in Table 5.1: DENSE use cases and related system performances.

Table 5.1: DENSE use cases and related system performances

Use case no.	Use case name	Target performance
1	Stationary object on the road (road debris)	The system shall detect a board shaped like a 185/55 R15 tire with 10% reflectivity at a distance of 50 meters.
2	Traffic jam ahead	The system shall detect a vehicle (traffic jam) ahead at 100m.
3	Pedestrian crosses the road	The system shall detect a pedestrian with 40% reflectivity in front of the car in a distance up to 50m.
4	Enhanced environmental awareness	The system shall estimate the prevailing road friction.
5	Drivable Area Awareness	The system shall detect the drivable area up a distance of 120 meters in the driving direction of the vehicle.

5.1 Perception and Detection Requirements

Resolution requirements are determined by the tire on the road. A common small vehicle tire dimension is 185/55 R15. This means that the tire is 185 mm wide when mounted in a vehicle, or 185 mm tall when resting flat on the ground. Low profile tires and truck tires are wider. Thus, compare 185 mm height of a tire with the vertical resolution at the target distance. With a minimum of two points on the target, the resolution has to be more than 185/2 mm, or a minimum 90 mm in the vertical dimension. The horizontal resolution can be relaxed somewhat as the tire resting on the ground is larger in the horizontal direction and it is not a stable position for a tire to be standing without support. The resolution is given as the instantaneous field of view (iFoV), which is the angle between resolvable objects. The minimal resolvable object *b* at distance *z* is then given by the expression, when iFoV is given in Radians:

$$b = z * iFoV$$

The distance at which a tire need to be recognized is determined by the allowable lateral acceleration for a lane change, or for coming to a stop if an evasive manoeuvre isn't possible if for example the adjacent lanes are occupied. Road friction and vehicle stability sets a limit on how rapid evasive manoeuvres can be allowed. Road friction braking ability determines minimum braking distance. These factors also have to fulfil passenger comfort limitations. Higher vehicle speed will increase the distance at which a tire needs to be recognized. If we assume normal highway speed, we consider a distance of 50 m as a lower range. Thus, the resolution required to recognise a tire will be assessed at 50 m distance from the vehicle. A resolution of 90 mm at 50 m therefore give the vertical iFov at 0.10 degrees. For simplicity, we elect to keep the horizontal resolution equal, even if the horizontal resolution could have been relaxed for the use case of recognizing a tire on the road.

We are assuming 10% reflectivity, which should be at the lower end of most clothing used - with the possible exception of velvet clothing fully covering the body. Tire reflectivity varies with surface properties and possible water films. Although one could argue for a lower reflectivity for a tire, we elect to keep 10% reflectivity for all tested objects as it simplified the assessment. Given that range (z) scale linearly with the reflectivity ρ of an object, reducing the reflectivity in half will also reduce the detected range in half.

Sensor lateral coverage – Field of View (FoV) determine how far to the side an object can be sensed. In urban settings or other low speed situations where the speed of the pedestrian can be higher that the vehicle (e.g., at launch of a vehicle from a stop sign or traffic light), a detection zone approaching the full 180 degrees of the frontal direction could be required. Installation locations in a vehicle place practical limits on the actual FoV to less. We have selected to use 140 degrees for desired horizontal field of view. Vertical FoV have to allow both coverage of overhead signs, vehicle loading and crests on the road. A vertical FoV approaching 40 degrees would therefore be needed.

Performance in adverse weather conditions depends on the ability of the sensor fusion system to utilize the degraded sensor data, as well as how much the visibility is degraded. The actual visibility and the type of weather condition will determine how much the senor data will be degraded. The road authorities in some locations impose reduced speed limits on the motorways when fog reduces the visibility of the unaided eye to less than 100 m. We therefore select to use 100 m for unaided visibility as the test condition and measure relative improvements in detectable range with the DENSE system as a measure of its improvements. Thus, a detection of an object at 150 m equate to an improvement of 50 % in range vs. the unaided eye. The system improvement may not be the same for all types and conditions of adverse weather. The measured improvement will depend on the type of and properties of atmospheric obscurants that cause the reduction in visibility. Improvements in detectable range for a targeted object in for example the spray behind a truck on the motorway will often differ from the improvements in fog or snow. Thus rain spray may not provide the same relative improvement in visibility as for example fog, and different properties of fog will likely provide different improvements in sensing visibility although the unaided eye provide the same visibility range.

We therefore need to measure the improvements under documented visibility conditions that reflect the differences in range for sensors operating in different wavelengths.

Sensor requirements

Table 5.2 provides a summary of the desired eventual sensor system specification which needs to cover the use cases defined in D2.2. [1] However, the full set of requirements may not be implemented in the system demonstrator due to time and budgetary restrictions. Thus, Table 5.3 given below summarizes the acceptable performance to demonstrate the proof-of-concept of the DENSE sensor system.

Table 5.2: DENSE target eventual system needs to cover all use cases

Parameter	Target performance	Remark
Hor. FoV [°]	140	180° is not feasible in a vehicle installation
Hor. Resolution [°]	0,1	
Hor. Accuracy [°]	0,1	1 Sigma
Vert. FoV [°]	40	
Vert. Resolution [°]	0,1	within +5 / -10°, outside factor 2...3
Vert. Accuracy [°]	0,1	1 Sigma
Range [m]	120	Reference targets: Board 2 x 1 m, 10% reflectivity Retroreflective number plate 0.18 x 0.1 m tilted upwards 45°
Range [m]	50	Reference target: Board shaped like a 185/55 R15 tire on the road 10% reflectivity
Range accuracy [m]	0,03	1 Sigma
Frame rate (full scan) [Hz]	25	
Temperature range [°C]	- 40 ... + 85	
Raw data: Point cloud	Range provided in Cartesian or polar coordinates	

Table 5.3: DENSE target sensor performance to show proof-of-concept of a DENSE system.

Parameter	Target performance	Remark
Hor. FoV [°]	24	Align with current ADAS cameras
Hor. Resolution [°]	0,1	
Hor. Accuracy [°]	0,1	1 Sigma
Vert. FoV [°]	25	Exclude very hilly roads
Vert. Resolution [°]	0,1	within +5 / -10°, outside factor 2...3
Vert. Accuracy [°]	0,1	1 Sigma
Range [m]	120	Reference targets: Board 2 x 1 m, 10% reflectivity Retroreflective number plate 0.18 x 0.1 m tilted upwards 45°
Range [m]	50	Reference target: Board shaped like a 185/55 R15 tire on the road 10% reflectivity
Range accuracy [m]	0,03	1 Sigma
Frame rate (full scan) [Hz]	20	Align with current ADAS cameras
Temperature range [°C]	- 10 ... + 65	
Raw data: Point cloud	Range provided in Cartesian or polar coordinates	

A mobile road state sensor is an optical remote instrument, which resolves the state of the road surface by means of spectroscopy. Typical reported parameters are estimated friction level, detected film thicknesses for water, ice and snow, and surface state categorization to classes such as dry, moist, wet, icy, snowy, slushy etc.

One of the goals of developing and testing such an instrument in DENSE is to find out what kind of possibilities this measurement capability could enable for the automated driving vehicle. Areas with potential synergies that have been identified in initial discussions with the OEMs include (i) providing additional surface-related information to the CNNs at the teaching phase, (ii) optimizing active suspension settings / body roll based on the average conditions of the driving surface, and (iii) providing additional information about the test environment when evaluating the complete DENSE demonstrator vehicle. Overall, road state sensing is a novel area for automated driving vehicles, and the eventual benefits and limitations of road state detection capability need to be further clarified with actual tests.

Among the most important high-level requirements for such an instrument is to provide information about estimated friction level between the vehicle tire and the surface. This should preferably be done by monitoring a sample area on the vehicle pathway, either underneath the vehicle, or then from a short (typically 0.5-5 m) distance towards either the back or the front of the car. Technical requirements that have been identified during WP2.3 relate to preferred measurement response time, accuracy of the measurement results, eye-safety aspects etc.

Road Surface Condition

Table 5.4: DENSE target Road Surface Condition Sensor classification provide the target performance of the road surface conditions, and Table 5.5: DENSE Desired Road Surface Condition Sensor – general target specifications provide a summary of the remote road state sensor.

Table 5.4: DENSE target Road Surface Condition Sensor classification

Parameter	Target performance	Remark
Road state	Classification to DRY, MOIST, WET, ICE, SLUSH, SNOW	Mandatory
Film thickness for water	1 mm	Optional
Film thickness for ice	1 mm	Optional
Film thickness for snow	0.5 mm water equivalent	Optional
Estimated level of grip	Poor, Medium, Good	Mandatory
Visibility	Poor, Medium, Good	Optional
Road surface temperature [°C]	1	Optional
End result reporting interval [Hz]	Adjustable, 1...4	Mandatory

Table 5.5: DENSE Desired Road Surface Condition Sensor – general target specifications

Parameter	Target performance	Remark
Laser class	Eye-safe	
Stand-alone capability	Sensor is an independent (stand-alone) unit, which internally resolves and then reports the end result parameters.	
Connectivity for end result reporting	Typ. including RS-485 or Ethernet	
Measurement distance range	40…120 cm	Set by optics design targets, technology typically allows for max. distances in the range of 15 m, angle spec allowing;
Measurement angle	30…85 deg from horizontal line	90 deg. should not be used to avoid specular reflection
Size of measurement area	Typ. diameter 10 cm	Typically pointed to wheel track
Mounting location / location of measurement beam	Variable, typ. mounted so that road surface is measured from behind or from below of the vehicle. Fixed beam location.	Forward looking geometry is possible but could be more prone to dirt accumulation on windows.
Raw measurement cycle speed	Typ. 25 ms	Duration of the internal measurement cycle for deriving one raw set of reported parameters
Sensor speed of response to a step change in road condition	Typ. 1 s, adjustable	Amount of internal averaging that is applied to the raw results.
Tolerance against other light sources	Tolerates normal ambient light changes. Other on-board lidar SWIR illuminators should not illuminate the measured spot on the road.	

Remote road state sensors are typically designed in such a way that the measurement performance is optimized for the most common surface types, i.e. old and new asphalt, as well as old and new concrete.

System needs (for all use cases)

The road state sensor is a stand-alone measurement unit, which interfaces with the host-PC by either using a socket-type Ethernet connection or a serial-line. It is required that a two-way machine-to-machine command-line interface, data recording and data time-stamping capabilities are implemented at the host-PC. In further data processing and analysis, the integrity of the recorded road surface result data has to be verified by message checksum comparisons.

5.2 Vehicle integration and packaging requirements

Besides the regular vehicle integration aspects of sensors, its connections and processors, there are also some specific considerations for the equipment included in the DENSE system, especially its sensor suite.

The vehicle integration of a sensor is the source of the most significant interactions between sensor and vehicle. There are four sensor types used in DENSE: RADAR, LIDAR, gated camera, and road state sensor. There are different integration and packaging factors for each of the sensor types:

RADAR

The RADAR uses a cover – radome – over the area of the senor where the radar beams are emitted and received. The transmission and reflection rates on boundary surfaces depend on many factors, such as the angle between radar beams and cover and the polarization direction of the emitted RADAR beam. This means that the influence of the specific radome design must be taken into consideration. This influence increases with larger angles. A radome consists of a plastic cover with a multi-layer structure of material with different permittivity and loss tangent. Effects like signal attenuation, reflection and diffraction have to be taken into account. This resulting performance reduction of the RADAR sensors can be minimized by optimization of several parameters.

Two installation concepts for RADAR sensor are in use:

- with optical cover of the RADAR sensor
- without optical cover of the RADAR sensor

The optical cover makes the RADAR sensor more design-friendly but this cover will attenuate the RADAR beams and might change the angle characteristics. One usual option to cover a RADAR is the use of a radome that is specifically designed for a certain RADAR sensor and mounting position. This leads to optimized results regarding the influence of the RADAR performance (angle accuracy and sensitivity) and uniform behavior as only a limited amount of cover designs need to be characterized. The effort to design and test such a radome is very high and can therefore only be considered for large volume series production vehicles.

The second option is a mounting position behind a suitable vehicle structure that is compatible with radar beams, such as the plastic bumpers of a vehicle. Unfortunately, the bumper usually has more variations in design and surface properties. One example is the effect of different paint types, such as metallic paint.

In the DENSE project we prefer to minimize the considerations mentioned above in order to focus on assessing the core to the DENSE project, such as performance increase by the used sensors and the computational method. We will therefore mount the sensors in a way that they are not covered by an additional surface e.g. in the area of the radiator grill structure. The used RADAR sensors already have a suitable radome structure design to cover the antennas. We therefore intend not to mount the RADAR sensor behind any vehicle structures. RADAR sensor shall be fitted with installation means allowing an alignment at the end of the vehicle assembly process or in the workshop.

The future automotive RADAR sensors shall operate at 79 GHz band. The European Commission decision 2004/545/EC required that this band is made available in all EU member states. The use of the 24 GHz band shall be avoided. This band is also used by other radio services that would suffer interference if too many radar devices were operated simultaneously in the same area. In addition, the radar would be required to be switched off within a certain distance of radio astronomy stations, to avoid interference.

LIDAR

The LIDAR sensor is an optical sensor that requires line-of-sight. The integration choices therefore have to consider obstructions in the viewing direction over the full field of view of the sensor. Installation inside the vehicle is therefore more problematic if large viewing angles are desired. A sensor with a wide viewing angle placed at the outside of the car needs an aerodynamic suitable mounting (to avoid wind noise) and a cushioning in case of impact.

In contrast to a camera, optical distortion is not as sensitive when measuring the amount of received photons. This reduces the optical distortion requirements of the sensor surface considerably. An optical aperture covered with dirt and water will attenuate the sensor signal, as with any optical system. Means to detect dirty or other effects that influence optical transmission is therefore necessary so that cleaning measures can be initiated and if necessary to inform the driver.

Gated SWIR camera

The gated camera will be mounted facing forward. It is desired to mount front view cameras behind the windshield of the automobile and close to the rearview mirror. This position has the advantage in a wide field of view, and yet being protected from ambient conditions and temperature by the windshield. In addition, the windshield in front of the camera is swept by the wipers thus ensuring a clean view. Transmission properties of the windshield in the chosen wavelength has to be considered, and a "cut-out" in the normal sun-blocking filter in the windshield may be necessary.

Road state sensor

The mounting location of the road state sensor should ideally be facing forward as much as possible, while considering the optical limitations coming from shallower angle to the road surface when the aiming location of the sensor moves forward. Keeping the road state sensor operational especially under bad weather conditions requires the ability to keep the sensor clean. This would imply manufacturing of a special case and additional cleaning which is out of scope of the DENSE project. Instead, it may be preferable for the demonstrator to mount the road state sensor in a location at the back of the vehicle to demonstrate viability of the approach.

5.3 Vehicle integration requirements

A description of the boundaries of the sensor suite and its integration in the vehicle's communication system is needed for a whole description of the integration of the system in the vehicle. How the system shall interact with the driver and other vehicle systems are of course essential to achieve the targeted benefits in an eventual system released to the public. Such interaction likely consists of at least information to the driver's Human Machine Interface (HMI) as well as any mitigation actions such as braking and/or steering. These are extensive topics, but not unique to the scope of the DENSE project. We will focus on integration aspects necessary to implement the DENSE demonstrator in the target test vehicle.

System control of essential driving functions such as steering and braking require a very high level of validation before use in vehicles on public roads. Instead, we will limit our interaction to inform of the system's performance and outputs on a separate, dedicated display. As some events can be fast, or happen unexpectedly, we aim to record the data to allow play-back in a desktop environment at a selectable speed - either higher or slower than during recording.

5.4 Functional safety level requirements

Functional safety for automotive applications is defined as the absence of unreasonable risks due to hazards caused by malfunction of an electrical and/or electronic system in passenger cars. Functional safety is an extensive topics, but not specifically unique to the scope of the DENSE project. The DENSE project will therefore focus on the areas that concerns functional safety of the DENSE demonstrator and functional safety that is inherent with the use of the selected sensor technology, specifically

1. Eye safety
2. Sensor performance and robustness in various environmental conditions
3. Capability of diagnosing safety relevant failure modes of the sensor systems and the prevention of providing incorrect sensor data that could lead to a degraded detection performance of the sensor fusion algorithms (and ultimately a hazardous output of a future system)

The safety of the demonstrator system is evaluated as follows:

- Eye safety: The laser illuminators may generate IR light that can be harmful for the eyes. The demonstrator shall fulfill the standards of eye safety. The eye safety analysis shall be performed according to the latest release of the international standard for safety of laser products (currently IEC 60825-1:2014).
- The DENSE demonstrator system shall not be connected to any of the vehicle actuators (engine control, brakes, steering) and thus an erroneous output should not lead to hazardous operation of the vehicle. Hence, there are no functional safety requirements on the demonstrator system.

The following needs concerning the focus areas 2) and 3) shall be addressed in WP3 – WP6.

Gated SWIR camera:

- Identify (by analysis) failure modes associated with controlling sensor operation, synchronization of the laser illuminator, measurement of objects, synchronization and transmission of sensor data.
- Prevent safety violation of eye safety standard by design or by self-diagnosis.
- Provide sensor self-diagnosis covering a sub-set of the identified failure modes, which are sufficient for the demonstrator integration.
- Protect the transmission of camera image data from data corruption.

LIDAR sensor:

- Identify (by analysis) failure modes associated with controlling sensor operation, synchronization of the laser illuminator, measurement of objects, synchronization and transmission of sensor data.
- Prevent safety violation of eye safety standard by design or by self-diagnosis.
- Provide sensor self-diagnosis covering a sub-set of the identified failure modes, which are sufficient for the demonstrator integration.
- Protect the transmission of point-cloud data from data corruption.

RADAR sensor

- Identify (by analysis) failure modes associated with controlling sensor operation, synchronization of the radar transmitter and receiver, measurement of objects, synchronization and transmission of sensor data.
- Provide sensor self-diagnosis covering a sub-set of the identified failure modes, which are sufficient for the demonstrator integration.
- Protect the transmission of radar image data from data corruption.

Fusion ECU:

- Identify (by analysis) failure modes associated with controlling sensor operation, synchronization and reception of sensor data.

Integrated fusion system:

- Measure and evaluate sensor performance and robustness in various environmental conditions.

5.4.1 Functional safety level of the fusion platform

ISO 26262 [3] is an international standard that defines functional safety requirements for the development of automotive Electrical and Electronic (E/E) systems. The first release of this standard is titled “Road vehicles – Functional safety” and was released in 2011. This version is an adaption of the Functional Safety standard IEC 61508 and targets E/E systems installed in series production vehicles with a maximum gross weight below 3500 kilogram. Functional safety for E/E systems in special purpose vehicles, such as trucks and vehicles for drivers with disabilities is out of scope of this standard.

Goals of ISO 26262 include:

- Provides an automotive safety lifecycle (management, development, production, operation, service, decommissioning) and supports tailoring the necessary activities during these lifecycle phases.
- Covers functional safety aspects of the entire development process (including such activities as requirements specification, design, implementation, integration, verification, validation, and configuration).
- Provides an automotive-specific risk-based approach for determining risk classes (Automotive Safety Integrity Levels, ASILs).
- Uses ASILs for specifying the item's necessary safety requirements for achieving an acceptable residual risk.
- Provides requirements for validation and confirmation measures to ensure a sufficient and acceptable level of safety is being achieved.

ISO 26262 defines 4 Automotive Safety Integrity Levels (ASIL): ASIL A, B, C and D. ASIL-A and ASIL-D are respectively the lowest and highest defined safety levels in the standard. Each level classifies the safety risk of a system and defines the level of risk reduction that is required to prevent specific hazards due to system failure.

Requirements for a systematic approach to identify the ASIL are described in ISO 26262-3 Section 7.4. The approach describes first the analysis of situations in which system misbehaviour may lead to hazardous events under correct and incorrect usage of the vehicle. Furthermore, hazards at vehicle level shall be described which may lead in combination with the identified situations to hazardous events.

ISO 26262 prescribes that each hazardous event shall be classified to a severity level listed in Table 5.6. Moreover, the operational situation of each hazardous event shall be assigned a probability of exposure listed in Table 5.7.

Table 5.6 Classes of Injury

	S0	**S1**	**S2**	**S3**
Description	No injuries	Light and moderate injuries	Severe and life-threatening injuries (survival probable)	Life-threatening injuries (survival uncertain), fatal injuries

Table 5.7 Classes of probability of exposure regarding operational situations

	E0	**E1**	**E2**	**E3**	**E4**
Description	Incredible	Very low probability	Low Probability	Medium Probability	High Probability

Next, the controllability of the hazardous event shall be classified to a class in Table 5.8. The event may be controlled by for example the driver or other occupants over the vehicle.

Table 5.8 Classes of controllability

	C0	**C1**	**C2**	**C3**
Description	Controllable in general	Simple Controllable	Normally Controllable	Difficult to control or uncontrollable

Finally, ISO 26262 prescribes that the ASIL shall be determined for each hazard event using the classification of injury, exposure and controllability using Table 5.9.

Table 5.9 ASIL Determination

Severity Class	**Probability Class**	**Controllability class**		
		C1	C2	C3
S1	E1	QM	QM	QM
	E2	QM	QM	QM
	E3	QM	QM	A
	E4	QM	A	B
S2	E1	QM	QM	QM
	E2	QM	QM	A
	E3	QM	A	B
	E4	A	B	C
S3	E1	QM	QM	A
	E2	QM	A	B
	E3	A	B	C
	E4	B	C	D

For the development of the DENSE fusion ECU for mass production, it is essential to assure functional safety. The developed ECU shall conform to ISO 26262 which means that functional safety shall be touched during all phases of development, including the overall management process.

Fulfilling to all requirements of ISO 26262 including a thorough analysis of hazardous situations and events is out-of-scope of the DENSE project. Rather, DENSE determines a preliminary ASIL of the fusion ECU by classification of the worst case event in the most hazardous use-case scenario described in D2.2 [1] which is DENSE-UC-2 Traffic jam ahead.

During this hazardous event, the injury is life-threatening since this high speed impact at the tail of a traffic jam is likely fatal (S3). The exposure is classified as high probable (E4) since traffic jams occur regularly and harsh weather conditions tend to increase its probability. Finally, this hazardous event is difficult to control since the driver will have less visibility during harsh weather conditions and is hence unable to detect the malfunctioning system in time. Moreover, for SAE levels 4+, the driver is out of the loop and is considered unable to take over control of the vehicle shortly after the malfunction is detected.

Considering these classifications, the ASIL of the fusion ECU for mass production is set to ASIL-D in line with Table 5.9. This assumes, however, that the fusion ECU is formed as a monolithic function block. However, the ISO standard explicitly provides that these hard requirements can be alleviated by dividing the driver's assistance function into individual functional parts (subnets) with lower ASIL requirements (e.g: ASIL C), so that these again result in the composition (e.g. C+C=D) in ASIL D again. To determine the hardware structure and the ASIL level of its function blocks further research is required.

According to the current state of the Art, there are no findings about how to implement ASIL D at an early fusion nor are findings about on how to proof that ASIL D level on an early fusion implementation (based on CNN). This is still the subject of research and should be treated in additional research projects based on the CNN structures for early fusion developed in DENSE.

On the other hand, no ASIL is defined for the prototyped fusion ECU developed in the DENSE project. The DENSE system, including the fusion ECU, will operate in a controlled environment where misbehaviour will not result in any injuries i.e. the severity of all hazardous events are classified to S0 leading to no ASIL.

5.5 Interfaces and calibration requirements

There are two basic approaches to handle independent sensors and other system components that need to interact with each other. That is either synchronous or asynchronous data collection. In a serial installation we need to reduce system cost as much as possible. That usually implies minimizing the part count and find clever ways to utilize the components, such as timing information, by all the units that need it. However, that also implies a careful synchronization and calibration. For the scope of the DENSE demonstrator we instead choose to allow the different sensors and other components to operate independently and instead utilize a common timing base. We select to use the widely available timing signal in the GPS system. All sensors and other units that provide data to the central fusion ECU will therefore time-stamp their collected data with the GPS time. The fusion ECU will thereafter synchronize all data points by interpolation. All sensors and other units providing data are therefore required to have a GPS puck connected and use its timing information to time-stamp each data point.

Each sensor provider is responsible to design and implement their own calibration and configuration function necessary to install, test, and validate their system. The validation of the test methods for the various sensors is the responsibility of each sensor provider, while the overall system validation responsibility resides in WP6. The defined use cases shall serve as the basis for validation tests on both the sensor level and on system level. The use cases therefore also provide pass-fail criteria.

6 Conclusion

The present document describes the requirements for the all-weather perception sensor and sensor fusion suite in order to achieve the use case scenarios described in Deliverable D2.2 - System needs and benchmarking. [1] The document specifies the sensor and sensor fusion platform requirements under fair weather in order to achieve the overall system requirements. The specifications are derived from deliverable D2.1 Characteristics of Adverse Weather Conditions [2] and deliverable D2.2 System needs and benchmarking in order to reach the overall system targets described in the referenced deliveries.

The present document aims to specify the performance requirements of the ultimate targeted system, despite the fact that the implemented demonstrator will have some limitations mainly on sensor field of view due to timing, budgetary, and financial reasons. The sensor specification for the demonstrator will however be selected to achieve a reasonable system demonstrator to prove the viability of the CNNs to reach the increased performance in adverse weather conditions. The demonstrator specification will be covered in delivery D3.1, System specification.

The sensor requirements are mainly determined by two use cases – detecting road debris and detecting a pedestrian coming in from the side. Road debris determines the resolution and range for a low reflective object, while the pedestrian use case determines the desired field of view. In order to be able to detect a difficult target such as a tire on the road, the resolution has to achieve at least two points in each direction on a tire resting flat on the road. That corresponds to a point size of 9 cm. For simplicity, we are assuming standard optics with equal resolution in both horizontal and vertical direction.

The remaining three use cases define other relevant aspects can be determined with the sensor data to define the functionality of the DENSE system. These are the ability of the classification system to recognize vehicles (traffic jam) ahead, estimate road friction, and estimate free space (drivable area) in front of the vehicle.

7 References

[1] W. Ritter, G. Duchamp, R.-M. Sibel, A. Tomatis, L. Hobert, T. Mahler, M. Kutila, A. Manninen, S. Laukkanen and H. Kuivala, “D2.2 - System needs and benchmarking,” 2016.

[2] M. Colomb, P. Duthon and S. Laukkanen, “D2.1 - Characteristics of Adverse Weather Conditions,” 2016.

[3] ISO 26262-2:2011, “Road vehicles — Functional safety,” 2011.