D3.2 Demo 2 Vehicle demonstrator for object detection in adverse weather conditions

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Related Work Package	WP3
Version/Status	2.1 | Final version
Issue date	29/11/21
Deliverable type	Demonstrator
Dissemination Level	PU

Project Acronym	SAFE-UP
Project Title	proactive SAFEty systems and tools for a constantly UPgrading road environment
Project Website	www.safeup.eu
Project Coordinator	Núria Parera | Applus IDIADA
Grant Agreement No.	861570

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.

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Document Distribution

Version	Date	Distributed to
2.0	23/11/2021	Coordination Team
2.1	29/11/2021	Submission in the EC System
2.1	17/03/2022	Approved by the EC

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Executive summary

This Deliverable falls under the SAFE-UP Project Work Package 3 “Active safety systems for vehicle-VRU interaction” and specifically under the Task 3.2 “VRU detection under bad weather conditions”. It is a purely technical document that targets to support the efficient monitoring of the technical developments for Demonstrator 2 “vehicle demonstrator for object detection in adverse weather conditions”.

The present document is the first of two deliverables related to Demo 2 and focuses on the scenario selection method, the setup and evaluation of two measurement campaigns, and a description of the Demo 2 simulation models under development.

A detailed description of the Demo 2 architecture and technical specifications can be found in the deliverable report D3.1 (SAFE-UP, Deliverable report D3.1, 2021).

The report is organized as follows: Section 2 presents an overview of the hardware architecture. In section 3, the scenario selection method and the used database are described, followed by a compilation of boundary conditions of the used test hall. As a result, the selected Demo 2 scenarios are described to close this section. Section 4 gives an overview about the developed algorithm subsystems and their current development status. Initial test results are presented in section 5, followed by a discussion, conclusion and a description of the next steps in section 6.

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List of abbreviations

Abbreviation	Meaning
CI	Crash Index
VRU	Vulnerable Road User
TTC	Time-to-Collision
P-CLwoSO	Pedestrian crossing left without sight obstruction
B-CR	Cyclist crossing from right while passenger car moves forward
KSI	Killed or seriously injured
FOV	Field-Of-View

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1. Introduction

This deliverable reports on the current development status of WP3 Demo 2. The goal of Demo 2 is to optimize VRU detection of active safety systems by considering bad weather conditions and taking into consideration real-world scenarios. The demonstrator will include a vehicle with advanced sensor configuration and VRU detection algorithms with the main focus on VRU detection in heavy rain and fog conditions.

The purpose of this document is mainly to support the technical coordination and monitoring of the Demo 2 development. It is therefore working as an internal technical document, supporting the work of the system developers throughout the process, as well as the related work that will be performed in T3.6 focusing on technical verification. This version of the deliverable focuses on the scenario selection, the first two of a series of measurement campaigns executed to build a data basis for the analysis of the influence of different bad weather conditions on several sensor types and the development of a weather filter for the simulation of sensor perception in adverse weather conditions.

An updated version of this Deliverable is scheduled for Month 26 of the project (July 2022), when Demo 2 has completed its development phase.

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2. Architecture

2.1 Demonstrator hardware architectures

Two Bosch development vehicles are used as Demo 2 test vehicles. The first vehicle, depicted in Figure 1, contains prototype high resolution radar, video and lidar sensors with raw data access but without object data output (in the following referred to as *Demo 2 vehicle*).

The second vehicle, depicted in Figure 2, is the same vehicle that is used as Demo 3 integration platform and contains closer to series radar and video sensors with object data output (in the following referred to as *Demo 3 vehicle*). Additionally, raw data access is available for the radar sensors.

A detailed description of the Demo 3 hardware architecture and technical specification can be found in the deliverable report D3.1 (SAFE-UP, Deliverable report D3.1, 2021).

Figure 1: The *Demo 2 vehicle*: a Bosch development vehicle with prototype high resolution radar, stereo video setup and lidar sensor.

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Figure 2: The *Demo 3 vehicle*: a Bosch development vehicle with close to series radar and video sensors.

3. Scenario selection

This chapter details the method for selecting scenarios for testing in a test hall as well as the specific boundary conditions of the test hall from THI. It is followed by a more detailed description of the scenario selection for Demo 2.

3.1 Scenario selection method

To be able to verify simulated results with real world performances in adverse weather conditions, scenarios must be identified, that are testable in a test hall under replicable conditions. While simulations have less boundary conditions, the tests in the test hall are limited to a bounded area and certain adverse weather conditions. The method for selecting scenarios, which reflect on the one side the most relevant safety-critical scenarios under adverse weather conditions and are on the other side testable in the test hall under repeatable conditions, is summarized in Figure 3 and described in the following.

Basis of the scenario selection is the crash data analysis performed in Task 2.1 of the SAFE-UP project, where four use cases for car-to-VRU crashes under adverse weather conditions are identified (SAFE-UP, Deliverable report D2.6, 2021). The relevant scenario clusters are further analysed based on their required space for testing in comparison to the test hall area. For the scenario clusters, which are testable in the test hall, the speeds of the VRUs and vehicles are further analysed. Therefore, the variable “initial speed” of the GIDAS data set is investigated for vehicles and bicyclists. It describes the speed before an intervention and the speed at the start of the critical situation which has led to a crash. For pedestrians the speed information is not included in the GIDAS data set, which is why values from literature are considered for pedestrian speeds. For each of the selected testable scenarios, one speed configuration is defined based on crashes involving killed or seriously injured (KSI) road users and one speed configuration based on all crashes involving injured road users. Therefore, the median values of the initial speeds in these groups are extracted. For pedestrians, the velocity of a running adult is chosen for the crashes with KSI road users and the velocity of a walking adult for the crashes with injured road users. Depending on the defined speeds and the test area, possible Time-to-Collision (TTC) periods are calculated to define how long the scenario can be approximately tested while remaining in the rain area. In general, the higher the speeds, the less time can be tested, where the objects are within the area where the weather condition can be simulated.

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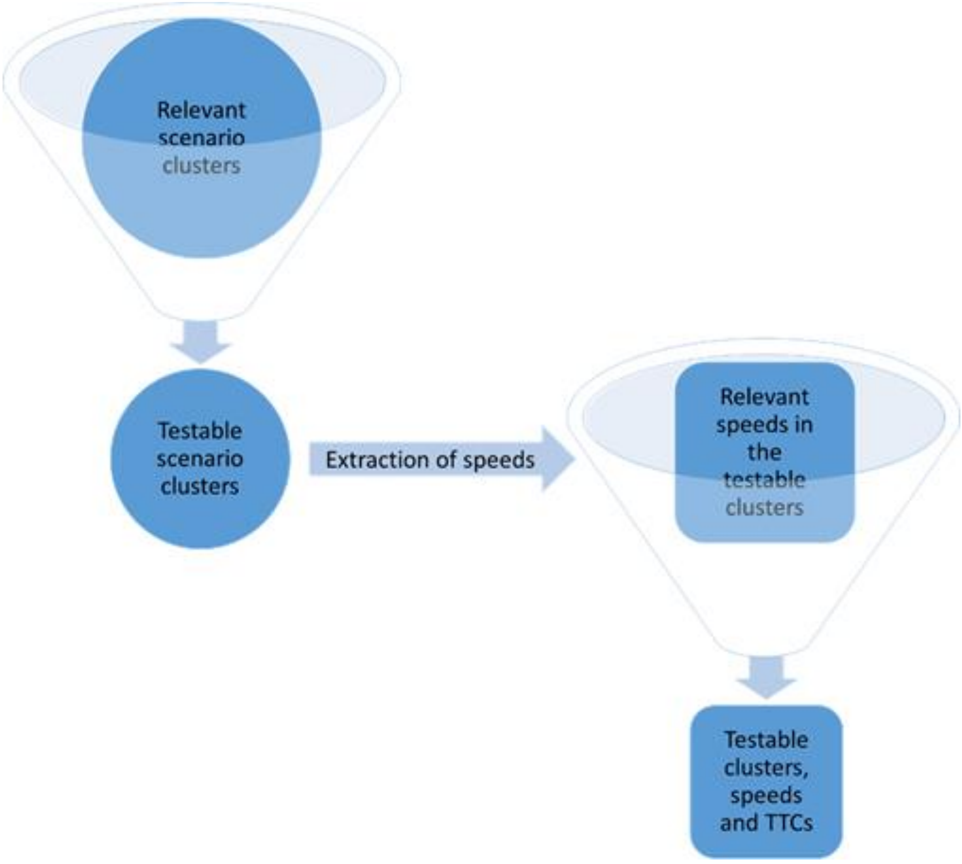

Figure 3: Summary of the method for selecting scenarios for the test hall.

3.2 Test hall boundary conditions

Within the scope of this project, weather influences and their effects on sensors play a significant role. One challenge is to ensure defined and repeatable tests under realistic weather conditions. These conditions can be ensured at the Center of Automotive Research on Integrated Safety Systems and Measurement Area (CARISSMA). With an indoor test area of 1800 m² (100m x 18m), the CARISSMA research and test center is an essential part of automotive research at Technische Hochschule Ingolstadt.

The rain surface is limited to 50m x 4m and has the following adjustable rain rates in mm/h: 16, 32, 66, 82, 98. The 12 segments, each 4.2m long, can be configured individually. The droplet size and distribution are adapted to the average precipitation in Ingolstadt (Germany) (Hasirlioglu & Riener, A General Approach for Simulating Rain Effects on Sensor Data in Real and Virtual Environments, 2020) (Hasirlioglu, Kamann, Doric, & Brandmeier, 2016).

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Figure 4: SAFE-UP tests under adverse weather conditions with a rain rate of 98 mm/h and a fog density with a resulting viewing distance of 5m.

For fog experiments, the hall can be used on a length of 50m and a width of 6m. The fog density is continuously adjustable and reproducible. The visibility is adjustable between 5m and 16000m and is measured with a Sick VISIC620 during the test.

Figure 4 shows the test facility during SAFE-UP tests in the most adverse weather configurations, meaning a rain rate of 98 mm/h and a fog density with a maximum viewing distance of 5m. A *4activeSystems GmbH* pedestrian target is placed 43m ahead of the car in both shown settings and barely visible for the human eye under the influence of rain. The pedestrian is not visible at all under the dense fog condition displayed above.

3.3 Selected scenarios for Demo 2

The four use cases for car-to-VRU crashes under adverse weather conditions identified in Task 2.1 of the SAFE-UP project are shown in Table 1. The focus of this analysis was on pedestrians and bicyclists as VRU types and on precipitation as it is significantly more prevalent in crashes with VRUs than other weather phenomena like fog. For more detailed information on the analysis and the selected use cases, it is referred to Deliverable D2.6 of the project (SAFE-UP, Deliverable report D2.6, 2021).

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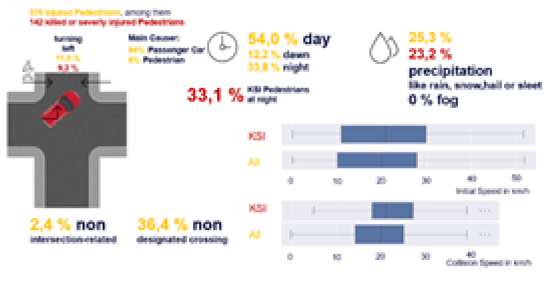
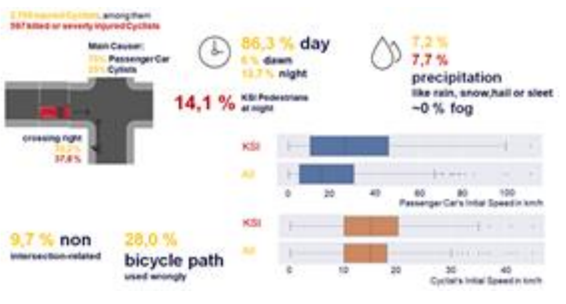
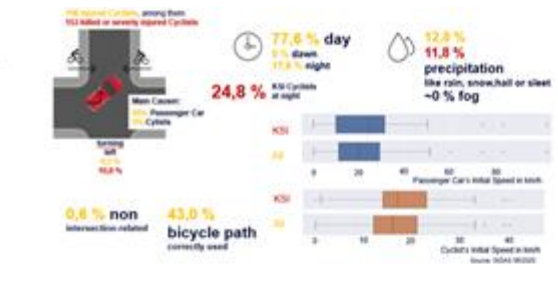
AWC-P1 scenario: P-CLwoSO	AWC-P2 scenario: P-PCTurnL
	
AWC -B1 scenario: B-CR	**AWC-B2 scenario: B-PCTurnL**
	

Table 1: Car-to-VRU scenarios recommended in D2.6 for consideration for safety systems with improved sensor performance (SAFE-UP, Deliverable report D2.6, 2021).

As the turning scenario for pedestrian as well as for bicyclists cannot be realized within the 50m x 4m rain area of the THI test hall, for both the proposed crossing scenarios are prioritized. More specifically, the clusters selected for testing under precipitation are the conflict scenarios P-CLwoSO (Pedestrian crossing left without sight obstruction) and B-CR (Cyclist crossing from right while passenger car moves forward).

From the boxplots with the initial speeds of the vehicles and the bicyclists given in Table 1, the median values can be extracted. One configuration is identified for the group of crashes involving KSI road users and one for the group of crashes involving injured road users. In the conflict scenario P-CLwoSO, the medians of the vehicles' initial speeds are 48kph (KSI) and 43kph (all injuries) respectively. In the conflict scenario B-CR, the medians of the vehicles' initial speeds are 26kph (KSI) and 15kph (all injuries) respectively and the medians of the bicyclists' initial speeds are 15kph for both groups. As pedestrian speeds, 8kph is chosen in the group of crashes with KSI road users (running adult) and 5kph in the group of crashes with injured road users (walking adult) (ASPECSS, 2014). The resulting scenarios and configurations are summarized in Table 2, where also possible TTC periods for testing are proposed. These are calculated based on how long the vehicle and the VRU can remain in the rain area with the identified speeds while considering also acceleration and braking distances. Due to the 4m width of the rain area, for the B-CR scenarios only up to 1sec TTC can be tested as with 15kph the bicyclist covers 4.17m per second. For the P-CLwoSO tests a TTC of 2 to 3 seconds can be realized due to the respective lower speeds of the pedestrian.

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To ensure the controllability for the driver also under rainy conditions in the test hall, it is planned to start the test with lower speeds than the proposed ones and increase it incrementally up to these values if feasible.

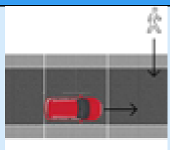
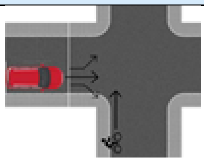
C2P/C2B conflict scenario	Schematic illustration of conflict situation	Vehicle speed	Target speed	Possible TTC
P-CLwoSO		48kph (KSI)	8kph (Running adult) (ASPECSS, 2014)	2sec
		43kph (All injuries)	5kph (Walking adult) (ASPECSS, 2014)	2-3sec
B-CR		26kph (KSI)	15kph (KSI)	1sec
		15kph (All injuries)	15kph (All injuries)	1sec

Table 2: Summary of selected scenarios for Demo 2 with suggestions for test speeds and TTCs.

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4. Demo 2 development status

4.1 Overall demonstrator scope

The overall scope of Demonstrator 2 is the development of an advanced sensor configuration and VRU detection algorithms for safe object detection in real-world scenarios in all weather conditions, with main focus on VRU detection in heavy rain and fog conditions.

To achieve this goal, special focus is given to an understanding of the relevant weather effects on different sensor types, as well as the modelling of these effects in simulation models as a first step. The results of this analyses and the developed simulation models will then be used to guide the development of an advanced sensor configuration and the VRU detection algorithms, which will be part of future work and handled in the subsequent Demo 2 deliverable report.

4.2 Weather filter

The development of new algorithms in the field of active vehicle safety requires extensive simulative tests. In this context, the perception and classification of the environment is an elementary component for planning and executing driving tasks. Particularly critical is the application under bad weather conditions. Extensive tests with natural weather conditions are usually expensive due to the necessary infrastructure and the high number of variables resulting from a multitude of target classes, weather conditions, and positions. It is necessary to transfer this testing effort into the simulation in order to be able to test more efficiently and widely. For this purpose, a weather filter is developed that limits the detection of ideal object data, based on the desired weather conditions. Input parameters for the weather filter are rain rate and fog density.

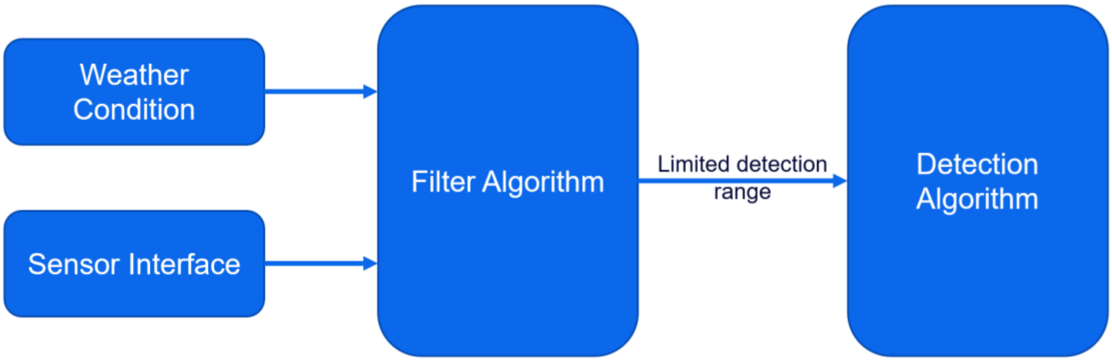

Figure 5: Preliminary architecture of the weather filter.

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Figure 5 shows a preliminary system architecture of the weather filter. The "Weather Condition" defines the desired weather and passes the values to the filter algorithm. The range of the rain rate and fog density is based on the testing capabilities of the CARISSMA test facility (see section 3.2), whereby intermediate settings are possible.

The second input to the "Filter Algorithm" is the "Sensor Interface" that provides objects within the Field-Of-View (FOV) of each sensor extracted from the simulation's ground truth. The information about object data comes from each sensor individually and is modified separately. It ensures the accurate representation of weather influences on different sensors. The filter algorithm limits the detection range per sensor type and object class based on the maximum range. THI follows two approaches to define the maximum detection range per object class.

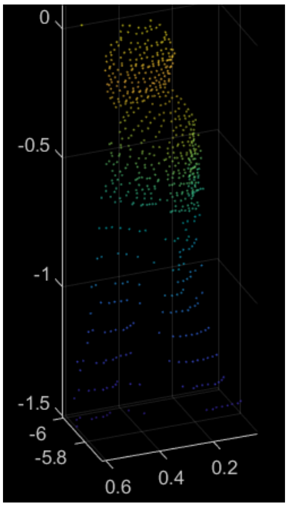

Figure 6: Lidar point cloud of the pedestrian dummy in relative distance [m] to the lidar sensor's origin.

The first approach is based on phenomenological modeling, using the empirical relationship of phenomena instead of the physical relationship. For this purpose, actual measurement data has been generated in a measurement campaign of several days in cooperation with Audi and Bosch at CARISSMA. The aim of the measurement campaign is the detection of VRUs under different weather conditions, as described in section 5. The measurements were performed at various distances, measurement angles and weather conditions (see section 5.1). An adult pedestrian dummy from *4activeSystems GmbH*, with moving legs, was used as the target. Figure 6 shows the lidar point cloud of the corresponding dummy.

The location of the vehicle and the target's position were always static, even though the dummy can move its legs on the spot. Throughout discrete measurements, a behavior model can be interpolated and thus modeled. The exact measurements that have been performed are described in section 5.

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The second approach is based on physical modeling comparable with (Zang, et al., 2019). The maximum detection range per sensor and object class is calculated physically, taking the weather influences into account as attenuation/noise. However, a purely physical description of the problem with all associated secondary effects and influencing variables (e.g. rain drops on sensors, multipath propagation) is not target-oriented for the efficient simulation and testing of novel algorithms in the field of acitve vehicle safety. Therefore, first existing weather algorithms are adapted to the test results. This will be done as a next step after the post-processing of the second measurement campaign, which is in progress by the time this document is published.

Both approaches have certain disadvantages in their applicability. The phenomenological approach is reduced to the test possibilities of the CARISSMA test facility and the overall testing effort. The limitations mentioned in Chapter 3.2 show that no long-range measurements under weather conditions are possible. In the physical approach, secondary effects are neglected. To compensate for disadvantages of both approaches, a hybrid variant consisting of both methods is investigated. The measurement data offers the possibility to validate/adapt the physical approach beyond the limits of the testing possibilities.

The implementation of the detection algorithm is currently being planned and depends, among other things, on the system architecture of the simulation. The timing of the object fusion thus determines the implementation.

4.3 Scenario simulation

Based on measurements with various weather conditions in the test hall of THI, which are described in section 5, a number of AEB simulations will be conducted.

While in most state-of-the-art simulations ideal sensor detection ranges are assumed, sensor detection ranges in simulations of this project are to be exemplarily adapted using results from the measurements with various weather conditions. Beside the changed sensor detection ranges due to adverse weather conditions, the simulation takes further scenario parameters into account (e.g. road friction coefficient).

The scenarios used for simulation are selected based on the accident analysis of Task 2.1, considering their identified use cases for adverse weather conditions, as described in section 3.3 As an output of this simulation analysis, the collision avoidability using adapted sensor detection ranges is to be assessed in comparison to the ideal sensor detection ranges.

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5. Initial test results for Demo 2

The measurement setup is built around the boundary conditions of the hall (see section 3.2), the demands from the scenario selection (see section 3.1) and the needed measurement data to develop the weather filter (see section 4.2). To cope with these requirements, two measurement campaigns are carried out.

5.1 First measurement campaign

Setup

The first measurement campaign utilizes the Demo 2 vehicle that is equipped with lidar, radar, and camera sensors (SAFE-UP, Deliverable report D3.1, 2021). Also, this vehicle allows access to only pre-processed sensor data. These are point lists for the radar/lidar and images from the camera. No fusion or classification algorithm processed this data. Figure 7 shows the measurement setup for the static measurements (note that only very few dynamic measurements have been carried out). The target is a pedestrian dummy facing to the left (from the vehicle's point of view). The dummy is always facing the same direction, independent of the vehicle's angle. The feet and legs of the dummy are moving to represent it walking on the spot. The dummy is placed in eight different positions. The vehicle remains at the same position but is turned around the z-axis of the radar sensor (front of the vehicle). Four angles for the vehicle are tested, to understand how the field of view affects the measurement (0 deg, 20 deg, 40 deg, 60 deg). The first measurement showed that 60 deg is not feasible since the reflections of the road boundary overload the radar sensor.

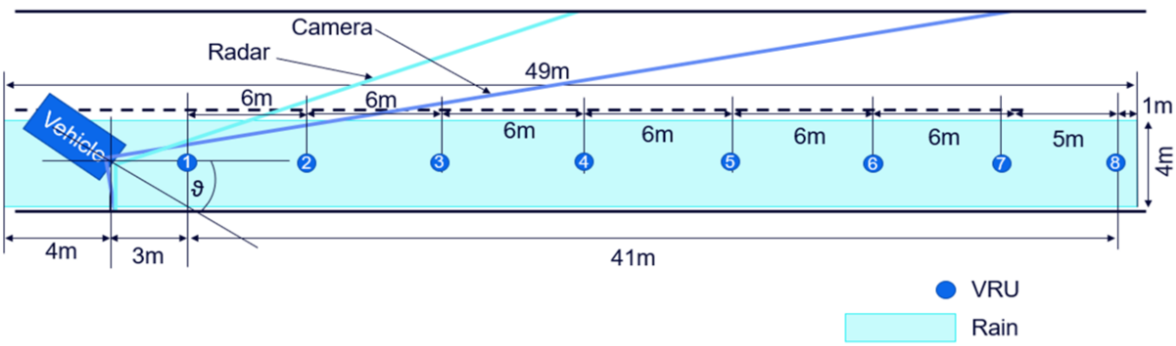

Figure 7: Measurement setup of the first measurement campaign (static measurements) inside the CARRISMA test hall.

To test the weather effects, five different weather settings are chosen: one measurement without any rain or fog, rain low intensity (16mm/h), rain high intensity (98mm/h), fog low

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density (> 20m of visual range) and fog high density (<20m of visual range). Additionally, for each weather setting, the hall is measured with and without a dummy.

Results

The measurement data contains detection points in space and time. One measurement usually took between 5-10 seconds. Since the dummy positions are known, the data is processed such that the position of the dummy is cropped out of the rest of the detection space. In this cropped-out volume, the detection points are counted and averaged over the detection time. Figure 8 depicts the results for the lidar, at 0 degrees, and for different environmental conditions. The degradation of the detection points lies in the expected area for the weather conditions.

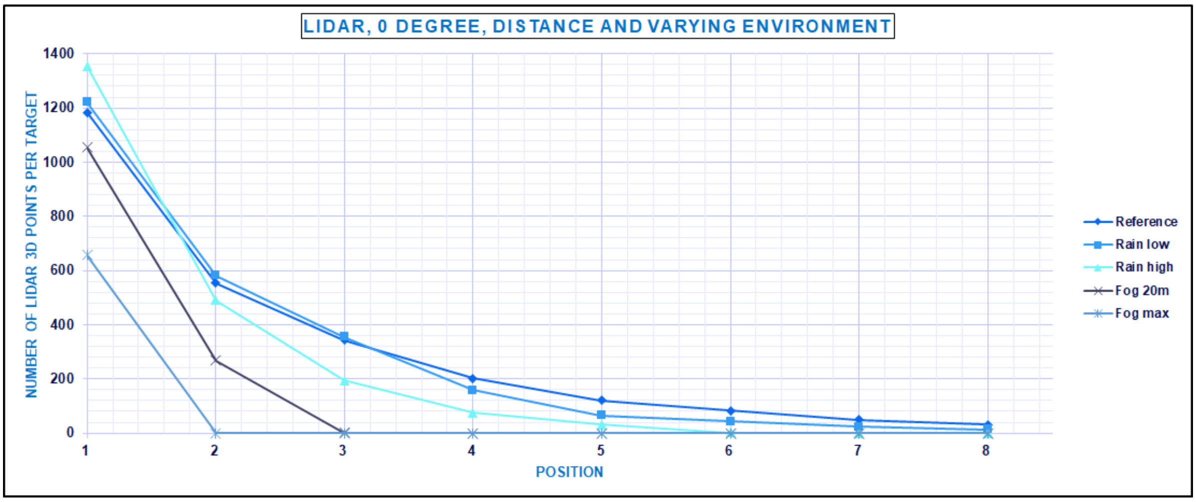

Figure 8: Lidar detection points for a pedestrian dummy at an angle of 0 degrees.

The same processing is done for the radar, and the results are shown in Figure 9. Note that the high amount of detection points for the high rain setting in the first position are due to the reflection of individual rain droplets. The results also lie in the expected area, sudden spikes lie in the expected error due to the noise nature of those measurements.

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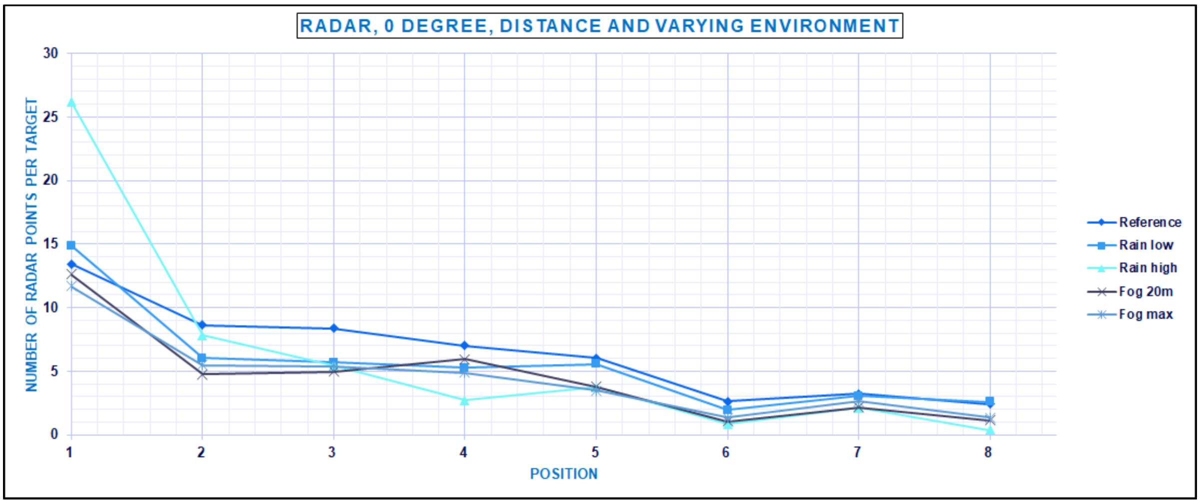

Figure 9: Radar detection points for a pedestrian dummy at an angle of 0 degrees.

Figure 10 shows the time evolution of one lidar measurement (0 deg, low rain, position 1). Here, one can see the oscillations of the detection points due to the dummy moving its legs.

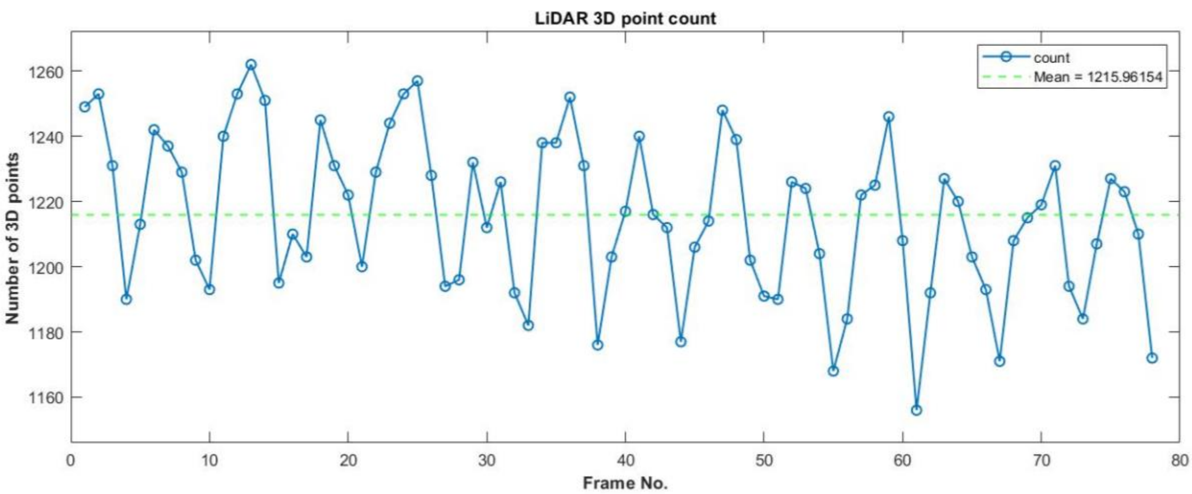

Figure 10: Time-resolved number of lidar detection points for a pedestrian dummy on position 1 in low rain at an angle of 0 degrees.

In contrast lies Figure 11, representing the same setting but with high rain intensity instead of the low intensity of the above plot. It can be seen that the detection is noisy due to random detections of rain droplets. The oscillations of the legs and feet are not clearly distinguishable anymore.

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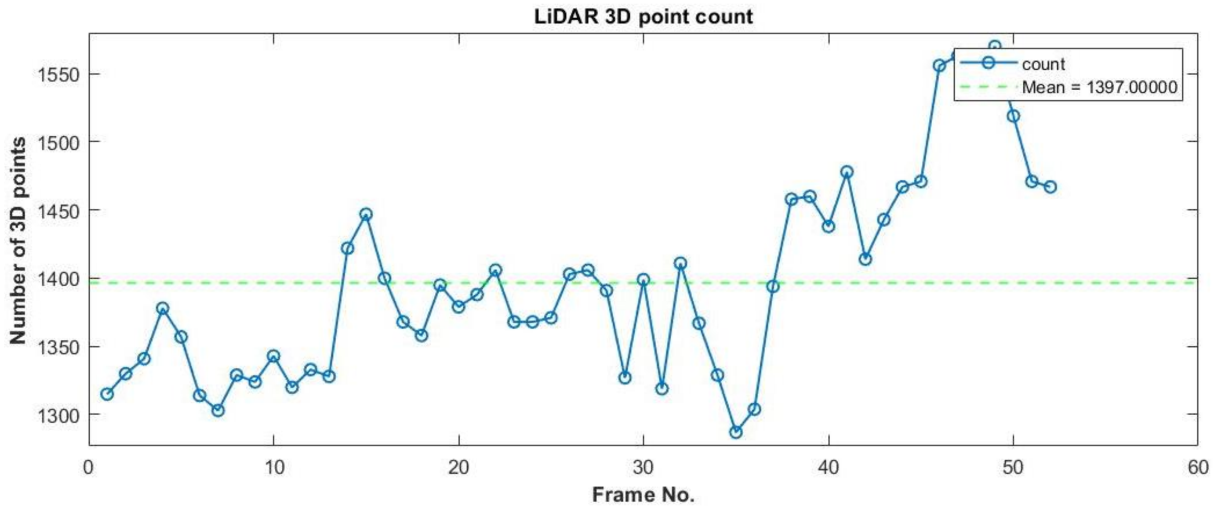

Figure 11: Time-resolved number of lidar detection points for a pedestrian dummy on position 1 in heavy rain at an angle of 0 degrees.

Lastly, Figure 12 shows a comparison for the camera. The left image shows a setting with low fog density. On the right image is the same setting with high fog density. The dummy is positioned at position 2, and the vehicle is angled at 0 degrees. It can be seen that fog, especially at high intensity, affects the camera substantially.

Figure 12: Exemplary camera images taken at low fog density (left) and high fog density (right).

The results of these first measurement clearly show the degradation of the weather effects on the lidar. The radar is mildly affected. The fog mainly affects the camera, but if rain droplets add up on the windscreen, the camera also gets blinded.

The results for the lidar and radar are further going to be used to develop the weather filter (see section 4.2).

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5.2 Second measurement campaign

Setup

The setup of the second measurement campaign is slightly different than those of the first campaign. First, the Demo 3 vehicle is used (SAFE-UP, Deliverable report D3.1, 2021). The vehicle does not have a lidar but runs processing software on the sensors. Thus, the results are more abstract and also represent the performance of the applied algorithm. Further, three targets are used: first, a pedestrian target (as in the first measurement campaign, see section 5.1), which can move its legs and feet on the spot, then a bicycle target and a powered two-wheeler (PTW) target. The latter two targets do not have any movability. All targets come from *4activeSystems GmbH* and are certified for radar measurements All measurements are static. The setup resembles the first campaign's (see section 5.1), but with 6 measurement points and the angles of 0, 16.7, 33.4 and 50 degrees. Also, the targets are rotated such that the angle between the vehicle and the target direction always maintains 90 degrees, which is more realistic for crossing scenarios. This setup is displayed in Figure 13. The Vehicle is positioned and rotated such that the scenario resembles a pedestrian crossing the road from the right-hand walkway.

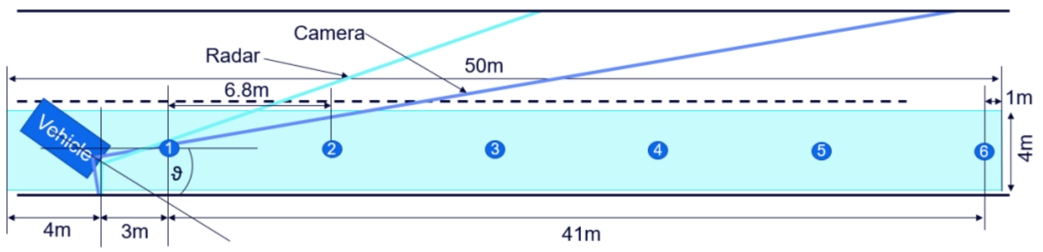

Figure 13: Measurement setup of the second measurement campaign (static measurements) inside the CARRISMA test hall.

The tested weather settings are: Without any, low rain (16 mm/h), medium rain (66mm/h), high rain (98mm/h), high density fog (<10m visual range), medium intensity fog (25 - 35m visual range) and low intensity fog (>45m visual range).

Results

The results at the time of writing this document are still in processing. The results will be presented in the subsequent Demo 2 deliverable report.

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6. Discussion, conclusions and next steps

The results of the first measurement campaign are promising. The weather effect impacts the sensors' performance, and the different characteristics of the sensors are noticeable. The results of the second campaign are still being processed, but it is expected that similar trends as in the first campaign are observable. On the other hand, the weather filter is currently being developed based on a hybrid approach: The physical weather effects on the dampening are analytically calculated, and secondary effects are modelled phenomenologically. The phenomenological modelling is realized by parameterizing the weather filter with the measurement data. The first results are promising, but the weather filter requires the measurement data from the second campaign for finalization. Lastly, the weather filter will be integrated into the autonomous vehicle model and handed over to work package 5.

Now that the effect of various weather conditions on different sensor types have been identified, and their modelling for simulation usage has been started, the next big step is the development of an advanced sensor configuration and VRU detection algorithms for safe object detection in real-world scenarios in all weather conditions. This topic will be covered in the subsequent Demo 2 deliverable report.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement 861570.