Trans Sec

Autonomous emergency manoeuvring & movement monitoring for road transport security

Deliverable 8.3

Test and Demo object detection and situation prediction

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Document Control

This deliverable is the responsibility of the Work Package Leader. It is subject to internal review and formal authorisation procedures in line with ISO 9001 international quality standard procedures.

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Executive Summary

Deliverable 8.3 documents integrating, testing and demonstration of several modules for object detection and environment perception developed until end of year 2. The perception modules work with several Cameras and LiDAR Sensors mounted at the Vehicle. Additionally the modules can provide information for the Local Dynamic Map (LDM).

The objectives for the object detection modules are:

1. Reliable detection of dynamic objects that are potential obstacles for the vehicle. Weak targets, like pedestrians or cyclists are of special interest.
2. Detection of static objects, which can be used for map matching.
3. Prediction of possible collisions by tracking the detected objects.

Test Vehicles and Equipment

LiDAR Sensors:	Ouster OS1 64 Layer
	Velodyne VLP-32C
Cameras:	Leopard Imaging LI-AR0231-GMSL-120H
	Logitech C270
GNSS receivers:	Trimble BX982
Positioning Services:	Trimble Centerpoint RTX,
Computer:	CarPC, Intel i7-6700TE, Nvidia GTX 1050Ti, 32GB Ram
Vehicle Model:	Mercedes-Benz Atego 823 Dumper with 7.5 to and 230 HP

Test drives

The test drives were conducted with the test truck Atego 823 in public road traffic in Stuttgart area. This is an urban and industrial, partly also rural area in a mostly hilly terrain.

Object detection results overview

- Light Detection And Ranging (LiDAR) based object detection provides accurate positioning and tracking of road users.
- LiDAR based object detection detects both static and dynamic objects.
- Camera based object detection provides high accuracy detection of specific classes.
- Possible collisions are detected and collision probability is calculated for a time horizon of one second.

Next Steps

To increase the performance of the perception modules, the truck will be equipped with additional cameras and LiDAR sensors, which will provide nearly 360° field of view (FOV).

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1 INTRODUCTION

TransSec is a research Project committed to deliver solutions for the rising amount of vehicle-based terror attacks. The work done by TransSec includes Modules for object detection, which is essential for the prevention of such attacks by active safety systems.

Deliverable D8.3 Test and Demo Object Detection and Situation Prediction is the documentation of the integration and demonstration of the object detection modules of work packages (WP)4-7 until the end of year two. The Object detection works on both LiDAR and camera. The Deliverables D4.1 and D4.2 describe the algorithms in more detail.

This deliverable includes tests of several software modules for the detection and tracking of objects. In particular, the object detection modules for camera and LiDAR, as well as the tracking and collision detection is tested. Therefore, the test also allows a comparison between camera and LiDAR based approaches.

The tests done in this report shows, that camera and LiDAR are already capable of accurate object detection and tracking. However, the integration done so far provides a limited FOV of 180° in front of the truck. This will be extended during the next year.

The next paragraphs will give an overview of the following chapters. In general, the chapters describe the steps of preparation, conduction and evaluation of the Object detection and situation prediction modules.

Chapter 2 “System overview” describes the object detection system including all the hardware and software components. The integration of the hardware into the test vehicle is described here too.

Chapter 3 “Testing” describes the preparation, i.e. the calibration, and the testing procedure. This chapter also includes the description of the test route.

Chapter 4 “Results” includes a description of the recorded data as well as analysis of special situations. This chapter also describes the strengths and weaknesses of the used approaches during the analysed situations.

Chapter 5 “Summary and Conclusions” summarizes the test results of the object detection modules and shows a conclusion based on them. This also includes an overview of the progress of object detection and the next development steps.

2 System overview

The TransSec object detection modules consist of several approaches for the detection of static and dynamic objects around the vehicle. The focus is on static objects that can be found in a map, like lane markings or traffic signs and on dynamic obstacles, which are mainly other traffic participants (other cars, pedestrians, etc.). Object detection and situation prediction concept

The TransSec object detection software uses cameras, LiDAR Sensors and Global Navigation Satellite Systems (GNSS) receivers as inputs for the detection and tracking frameworks and provide information about the surrounding objects. These are represented as 3D-cuboids with respect to the vehicle coordinate frame. Object detection with cameras is already well known and provides high performances at good sight. However, they are not capable of providing high accuracy data in bad weather conditions, at night or when blinded by direct sunlight. To obtain spatial information for the detected objects, an accurate calibration is necessary. LiDAR sensors on the other hand side provide point clouds of the sensor surrounding. Therefore, they provide very accurate spatial information, but suffer from lower resolutions. Additionally, the object detection is not yet so far developed as the camera based and these sensors are currently very expensive. By combining both types of sensors, we are able to compensate the disadvantages of each sensor.

The processing pipeline shown in Figure 1 creates 3D bounding boxes for dynamic objects. Additionally to the Bounding boxes, the relative position and speed of the objects is calculated. This information can be calculated very accurately by using the LiDAR Sensors, whose point clouds have cm level accuracies.

Overall, the software uses LiDAR, Camera and GNSS information to detect and track objects. For each object, the classification, the 3D bounding boxes, information about the movement and the collision probability are calculated. These algorithms are described in more detail in Deliverables D4.1 – D4.3 and D5.3 and in chapter 2.1.

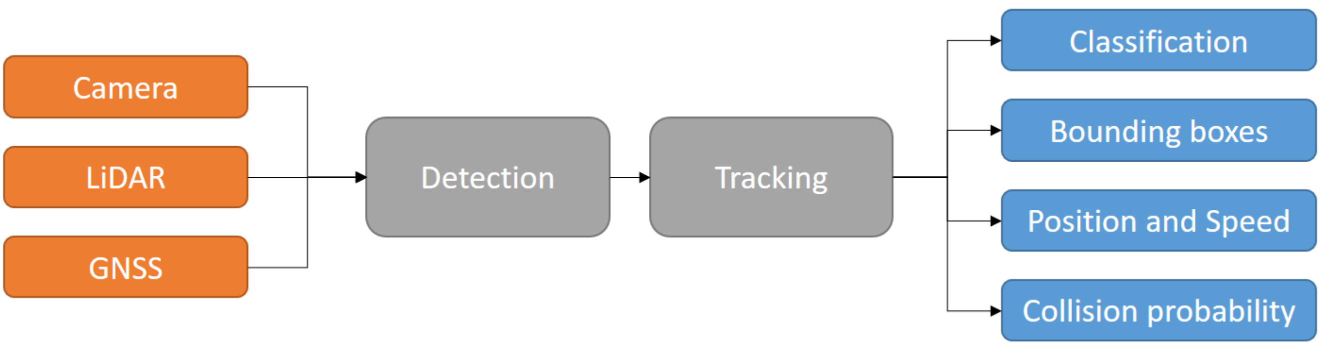

Figure 1: Project TransSec detection framework

2.1 Modules

This section describes some details of the software modules used for this test. This mainly contains the necessary inputs and outputs, as well as the functionality.

1. **Camera object detection**
   The camera based object detection uses images of different sizes as input and is able to calculate bounding boxes both in image and in 3-dimensional vehicle coordinates. For the calculation of the objects position in vehicle coordinates, an accurate calibration is necessary.

2. **LiDAR object detection**
   The LiDAR object detection is based on geometric relationships between points. This allows filtering out the points corresponding to the ground and grouping the remaining points to clusters. Finally, a 3-dimensional bounding box is created for each cluster. The only input is the point cloud in Cartesian coordinates. This allows detecting every physical obstacle around the car including static objects, like traffic signs and walls, as well as dynamic objects like pedestrians or cars. Additionally, a classifier is used for the detection of several dynamic objects in birds eye view (BEV).

3. **Tracking**
   The object tracking allows an estimation of the states of all surrounding objects. This includes the objects position and speed and is therefore required for the collision detection. This tracking works on both LiDAR and Camera objects. For the calculation, the ego vehicle movement provided by the GNSS receiver is used too.

4. **Collision detection**
   Based on the object detection, the states of the objects are predicted for the next second. This allows a calculation of the collision probability of each object in each time step during the next second. Thus very probable collisions are detected.

2.2 Vehicle integration

The truck used the demonstration drives is a Mercedes-Benz Atego 823 Dumper with 7.5 to and 230 horsepower. It is a series truck with no special equipment except a front camera, which detects road lanes markings and lane departure warning. The cabin has three seats, one for the driver and two for the passengers. Figure 2 shows the truck with installed sensors.

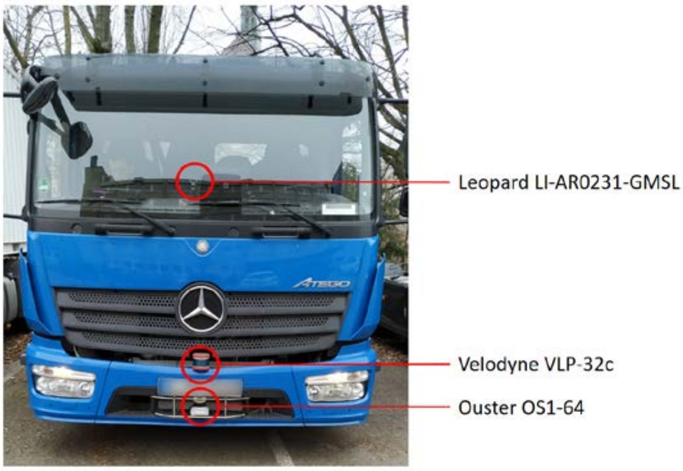

Figure 2: Atego 823 with installed LiDAR sensors, camera and GNSS antenna

2.3 Installed Equipment

This chapter gives an overview of the used Sensors, hardware and software. All the mentioned are built into the truck and supplied by the truck.

1. GNSS Receiver - Trimble BX982 with positioning service “Trimble Centerpoint RTX”. This is a high accuracy GNSS Receiver capable of positioning on cm level. For maximum GNSS reception, the GNSS antenna is mounted at the center of the roof of the truck.

Figure 3: Trimble BX982 (Trimble Inc., 2020)

2. LiDAR - Ouster OS1-64: A 64 Layer LiDAR Sensor with ±16.6° vertical FOV and 360° horizontal FOV. The LiDAR is mounted on the Front of the truck at a height of 32 mm.

Figure 4: Ouster OS1-64 (Ouster Inc., 2020)

3. LiDAR – Teledyne VLP-32c: A 32 Layer LiDAR Sensor with vertical FOV of +15° to -25°. The horizontal FOV is 360°. The LiDAR is mounted on the Front of the truck at a height of 66 mm.

Figure 5: Velodyne VLP-32c (Velodyne LiDAR, Inc., 2018)

4. Camera – Leopard Imaging LI-AR0231-GMSL-120H with 120° horizontal FOV and 73° vertical FOV. The image resolution is 1928 x 1208 pixels. The camera is mounted inside of the driver's cabin at a height of 1770 mm and 95 mm to the right of the vehicles centre plane.

Figure 6: Leopard LI-AR0231-GMSL (Leopard Imaging, 2019)

5. Camera – Logitech C270: RGB Camera with 60° horizontal FOV. The image resolution is 1280 x 720 pixels. The camera is mounted inside of the drivers cabin at a height of 1765 mm and 315 mm to the right of the vehicles centre plane.

Figure 7: Logitech C270 (Logitech, 2020)

6. Car-PC with Intel I7-6700TE, Nvidia GTX 1050TI, 32GB Ram and 1TB SSD. The computer is running on Ubuntu 18.04 LTS.

Figure 8: Car Pc (FleetPC-9) (CarTFT.com e.K., 2019)

Figure 9 and

Figure 10 show the FOV of the LiDAR sensors and cameras in BEV and side view. In the vertical direction, the cameras have a wider coverage field, while in the horizontal direction the LiDAR sensors have a wider FOV. For future tests, additional LiDAR sensors and cameras will be used to extend the coverage of the vehicle surrounding. D4.3 already proposes the position of the additional LiDAR devices.

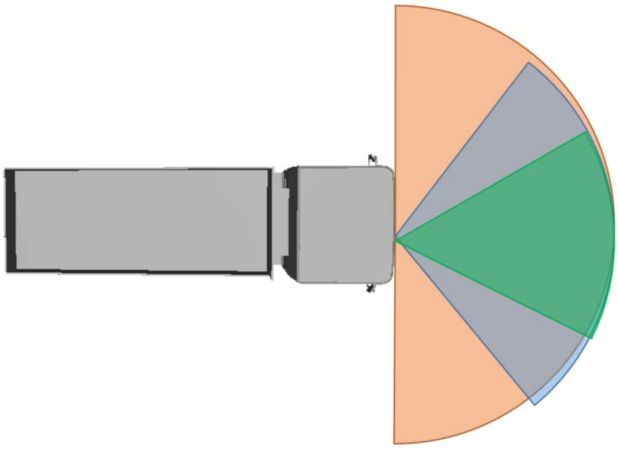

Figure 9: Horizontal FOV of both LiDAR sensors (orange) and cameras (Leopard – blue, Logitech – green)

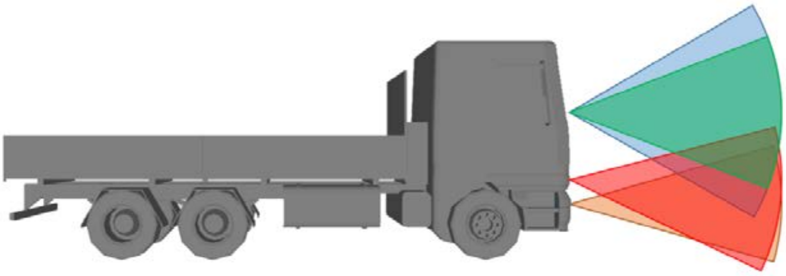

Figure 10: Vertical FOV of LiDAR sensors (Ouster – orange, Velodyne – red) and cameras (Leopard – blue, Logitech – green)

3 Testing

3.1 Testing Procedure

This Document describes the first integration of the Object detection and situation prediction modules at the end of year two. Therefore, the focus is on the general system performance, the limitations and possible system improvements. In this process, some special situations according to the TransSec use cases are analysed.

For this deliverable, two test drives with different hardware combinations are conducted. The first test drive uses the Ouster OS1-64 as LiDAR sensor and the Logitech C270 as camera. This test drive focuses on the analysis of LiDAR and camera object detection in different situations. The second test drive uses the Velodyne VLP-32c as LiDAR sensor and the Leopard LI-AR0231-GMSL as camera. During this test drive, the focus is on the sensor fusion, the tracking and situation prediction.

3.2 Test routes

The test route is located in the Stuttgart area which is a mostly urban and industrial area including also rural areas all in a mostly hilly terrain. Besides Stuttgart, the nearby city of Esslingen is included. Start and end of test routes is the location of Daimler Trucks Advanced Engineering in Stuttgart-Untertürkheim. The route can be seen in Figure 11 and is the same for both test drives

Figure 11: Test route of both conducted test drives

3.3 Test Conditions

The first test drive is carried out at the 17.01.2020 at 10:00 am with mostly sunny weather. Overall, 65 minutes are recorded. The recorded data include urban areas with pedestrian and bicyclist interaction, parking spaces, country road situations and high way drives. In all types of situations interactions with other motorized road users occur.

The second test drive is carried out at the 22.01.2020 at 4:00 pm at mostly cloudy weather. During this test drive, 56 minutes are recorded. Due to the same test route, the same types of situations occur.

Before the test-drives, the extrinsic parameters of the camera are calibrated using the method described in deliverable D4.3.

4 Results

During the test drives, the focus is on some specific situations, like city road crossings or tunnels. These situations are listed and analysed in chapter 4.1. For each of the situations, the results of the object detection is shown explanatory.

4.1 Situation analyzation

The recorded data include several driving scenarios. Deeper investigations are made for the situations:

- Tunnel
- City road crossing
- Highway
- Pedestrian crosswalk

Tunnel and City road crossing are also included in the TransSec use cases, while the highway is a special case of the one-way road. The pedestrian crosswalk scene can be compared to use cases with several pedestrians in close range to the truck, like the shopping zone.

4.1.1 Tunnel:

Tunnels are a special case for both camera and LiDAR sensors. For the camera, the lightning situation differs a lot compared to most outside scenes and especially the rapid light change at the entrance and exit are challenging. At the entrance, the image typically gets very dark, while it is blinded at the exit. Figure 12 shows such a blinding at the exit of a tunnel exemplary. The object detection algorithm suffers from both situations.

Figure 12: Blinding of camera at exit of a tunnel

Our investigations show, that the camera based object detection works well during the time inside of a tunnel, but much worse during enter or exit of the tunnel due to the rapid changes of the lighting conditions.

For the LiDAR detection, a tunnel is a special case too. Here, the sensor detects the ceiling and the walls and therefore creates points all around the ego vehicle. Figure 13 shows, that the algorithm generates some small objects at the ceiling and the wall. The detection of other cars works well while being inside of a tunnel.

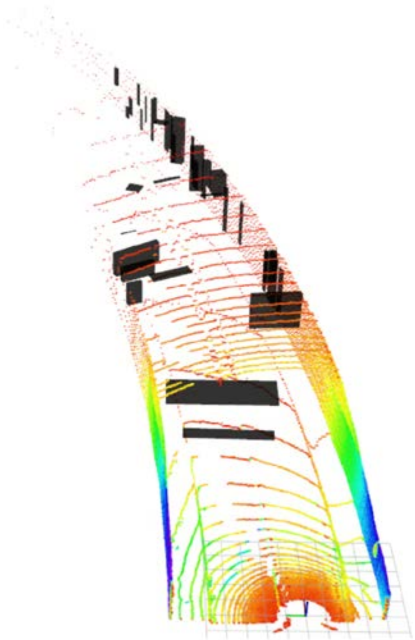

Figure 13: LiDAR point cloud inside of a tunnel

4.1.2 City road crossing:

City road crossings are of special interest due to the direct interaction with several types of road users, like cyclists, cars or pedestrians. Figure 14 shows an example of a city road crossing with several other cars. On the left hand side the camera based detection is shown, where several cars are detected.

In the middle, the LiDAR based detection is shown. This shows the capability of the algorithm to detect static elements, like the road signs. These objects are shown in grey. The road sign is marked in orange in both the camera and the LiDAR Frame.

Additionally, the cars detected by the LiDAR based algorithm are shown as red wireframes. On the right hand side, a BEV view of the LiDAR point cloud is provided. The turquoise side of the detected bounding boxes corresponds to the estimated front.

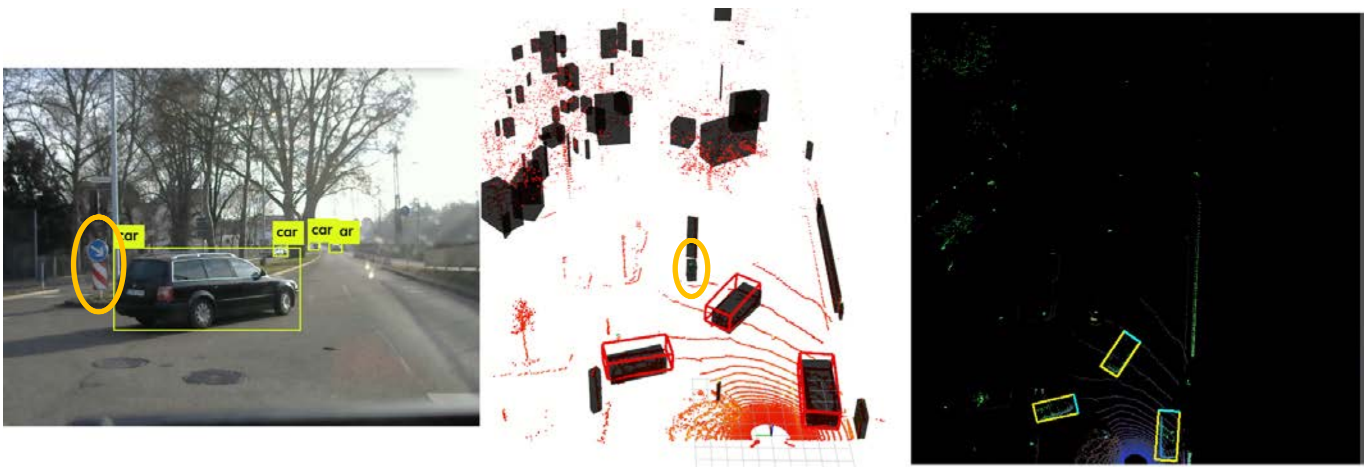

Figure 14: LiDAR and camera frame at a city road crossing with detected cars and static objects

4.1.3 Highway:

On Highways, the distance to other cars may be very large and the driving directions are separated from each other. Because the driving speeds are very high, other dynamic objects need to be detected in far distances. In Figure 15, a truck is detected at a distance of 96.12 m by both LiDAR and camera (marked in orange). In the camera Image, it is falsely classified as car. The LiDAR detector additionally detects the traffic sign (marked in green) and the guard rails on both sides of the street. Due to the low mounting position of the LiDAR, only the camera can detect the oncoming cars. The guardrails occlude this area for the LiDAR sensor.

Figure 15: LiDAR and camera frame at a highway

4.1.4 Pedestrian Crosswalk

The pedestrian crosswalk is a critical situation for safety systems due to the close range of vulnerable road users to the truck. Hence, a reliable detection and an accurate positioning are required for all dynamic objects. This situation is comparable to several TransSec use cases with pedestrians in close range, like the shopping zone. Figure 16 shows the object detection of the LiDAR and the camera for a pedestrian crosswalk. On the left, the camera object detection is shown. In the middle, the Point cloud is shown in 3D with all the detected objects marked in grey, the detected cars marked as red wireframes and the pedestrian as green wireframes. On the right, the point cloud and the detected objects are shown in BEV.

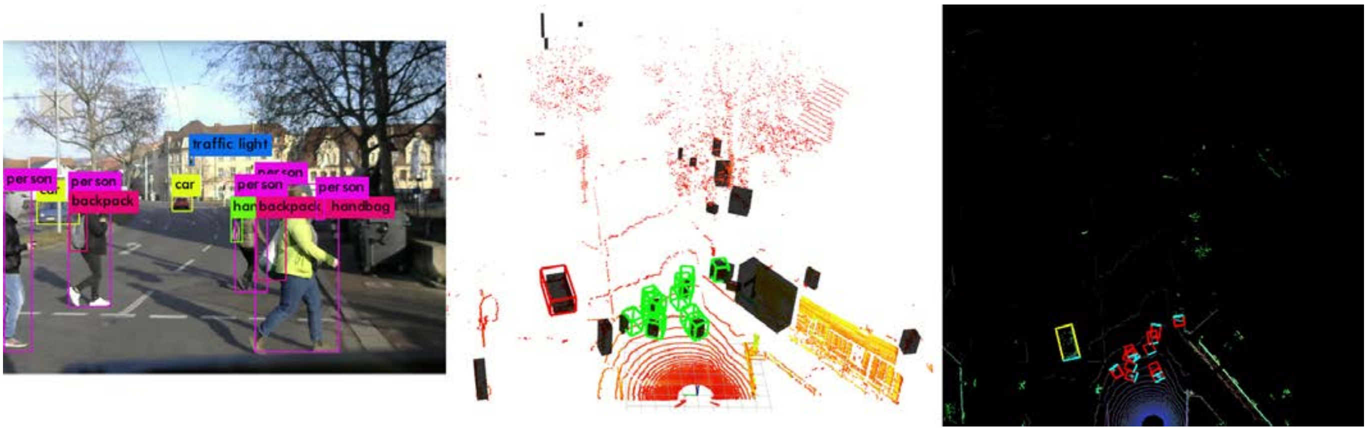

Figure 16: Pedestrian crosswalk with several pedestrians directly in front of the truck.

4.2 Sensor Fusion and collision prediction

All the objects detected by the camera can be projected to the LiDAR coordinate frame. Figure 17 shows an example of this projection, where cars are detected by both the camera (dark green) and the LiDAR (bright green). The 3-dimensional positions of the objects detected by the camera are based on the projection of the bounding boxes to the ground plane, which requires a precise calibration. Due to small calibration errors and the vehicle movement, a small offset between LiDAR and camera detection is possible. The red marked cars are detected by both the LiDAR and the Truck, while the orange marked ones are only detected by the camera.

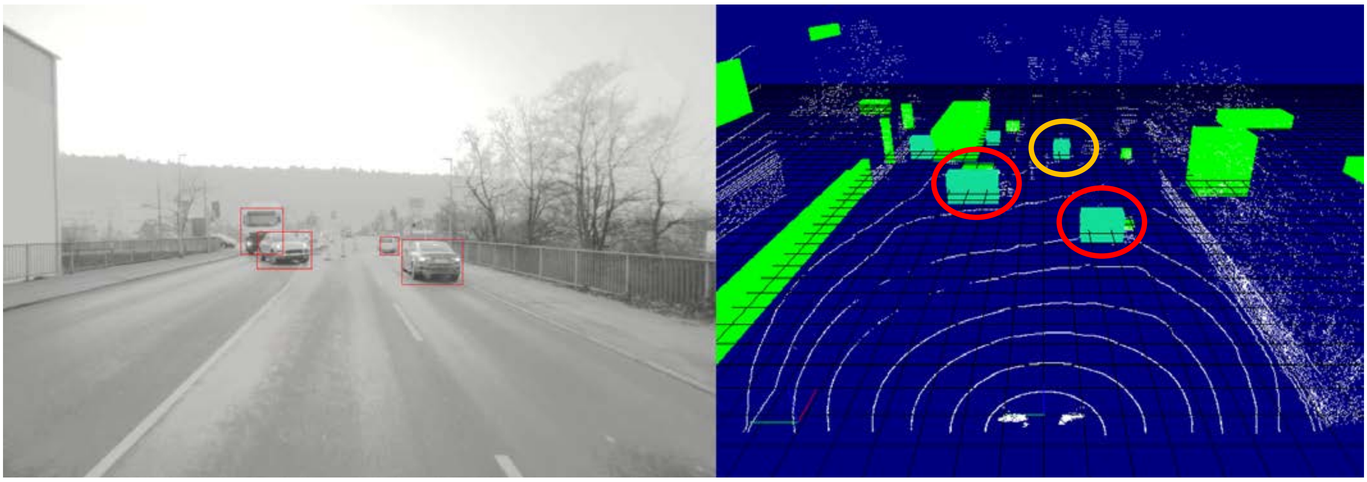

Figure 17: Urban situation with projected camera objects. Left – camera frame with object detection. Right – LiDAR frame with projected bounding boxes from camera detection (dark green) and LiDAR based object detection (bright green)

The test-drives show, that the camera detection is able to detect objects at higher distances in most situations. The reason is the higher resolution of the camera. Objects at high ranges only consist of few points of the LiDAR point cloud and are therefore difficult to detect. However, the LiDAR detections provide more accurate information about the object positions. Figure 18 exemplary shows the projection of the camera detections to the LiDAR point cloud. The orange marked car is detected by both the LiDAR and the camera. The Figure shows a small spatial offset between both detections on the right, where the LiDAR detection is the more accurate one. Objects further away are only detected by the camera.

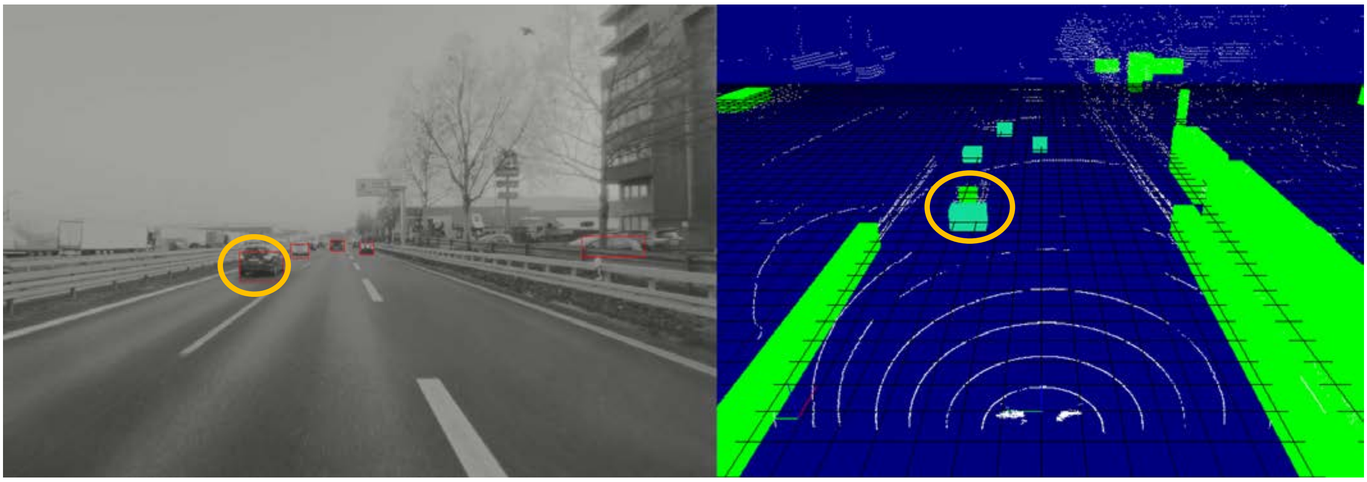

Figure 18: Highway situation with projected camera objects. Camera objects in dark green, LiDAR objects in bright green.

The object tracking on top of the detection estimates the states of all the dynamic objects and therefore allows the prediction of them during the next time steps. The collision detection module utilizes this for the calculation of the collision probability during the next second. Figure 19 shows the current position of the ego vehicle (green) and two more cars (red). The blue bodies show the estimated path of all vehicles during the next second. On the right, the estimated collision probability is shown.

Figure 19: Collision detection including two cars

Up to this processing step, all modules work passively and only provide information about the trucks surrounding. The collision detection is the prerequisite for active safety functions, which can be explored in further steps.

5 Summary and Conclusions

Deliverable D8.3 “Test and Demo object detection and situation prediction” documents the integration and testing of camera and LiDAR based algorithms for detection of static and dynamic objects. This also includes a module for detection of collisions and their probabilities. The tests show the results of the development until end of year two.

The test drives are conducted with the test truck Atego 823 in public roads in Stuttgart area. For LiDAR detection, the Ouster OS1 and the Velodyne VLP-32c are used. The camera detection used the Leopard LI-AR0231-GMSL and the Logitech C270. Additionally, the Trimble BX982 GNSS receiver is used for positioning.

The tests carried out investigate the object detection in different situations, like urban areas, country roads and highways. The combined object detection of camera and LiDAR works properly in almost every situation, while the standalone detections of each sensor show disadvantages in specific situations. In general, the camera suffers from bad lighting situations, like blinding, darkness or fog. At good lighting situations, the camera is able to detect objects, like cars in farther distances, but produces less accurate positioning results compared to the LiDAR. The camera based detection is restricted to specific classes, like cars or pedestrians, while the LiDAR sensor can detect every obstacle due to a geometric approach. However, classification is more accurate using a camera. Due to the mounting position of both sensors, in several situations, the camera is able to detect objects in areas, which are occluded for the LiDAR sensor. The situation prediction module is able to detect possible collisions and their probability.

This leads to the conclusion, that both sensors are necessary for a sufficient environment perception. The combined object detection together with the collision detection shows promising results to be used for collision avoidance. The integrated system has a limited field of view for both the camera and the LiDAR. In future steps, additional cameras and LiDAR sensors will extend this. Thus, a holistic environmental perception will be achieved.

6 ABBREVIATIONS AND ACRONYMS

Abbreviation	Description
LDM	Local Dynamic Map
LiDAR	Light Detection And Ranging
FOV	Field Of View
WP	Work Package
GNSS	Global Navigation Satellite Systems
BEV	Birds Eye View

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