TeamMate System Architecture including open API for 2nd Cycle

Project Number:	690705
Classification	
Deliverable No.:	D.5.5
Work Package(s):	WP5
Document Version:	10
Issue Date:	31/12/2018
Document Timescale:	
Start of the Document:	09/11/2018
Final version due:	31/12/2018
Compiled by:	
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Executive Summary

This document presents the different baseline cars (CRF, ULM and VED) and shows their software and hardware architectures. These architectures highlight their abilities and capacities and some critical and safety aspects that they can not deal with.

1 Introduction

This document is dedicated to the description of the baseline cars. The demo-cars owners (CRF,ULM VED) recall their baseline scenario and describe the correspondinghardware and software architecture. This description helps to highlight the disadvantages of such architectures according to risky scenarios or the unability to perform certain tasks (roundabout passing, overtaking …).

2 CRF baseline car

For the baseline (BL) car implemented in CRF vehicle, we mainly focus on the Human to Automation Cooperation, as described in the next paragraph.

2.1 Eva Scenario

The Eva scenario deals with the roundabouts, in extra-urban or urban roads. As in the other scenarios, also for Eva case, we have two types of interactions: Human to Automation Cooperation (H2A) and Automation to Human Cooperation (A2H). In addition, there can be two cooperative modes: in perception and/or in action (following the cooperation modes of Hoc, described in deliverable D1.1 “Definition of framework, scenarios and requirements”, at the beginning of the project).

In this scenario, before approaching the roundabout, the CRF vehicle travels in automated mode. What happens if the TeamMate system is implemented or not, it is described in the following two paragraphs (sections 2.1.1 and 2.1.2). After the roundabout, if the external conditions are appropriate and the driver agrees, the TeamMate car can activate again the full automated mode.

2.1.1 Baseline Scenario

In the baseline scenario, when the BL car approaches a roundabout, it “knows” that it won’t be able to handle it in a safe way (missing infrastructure, limitations of sensors field of view, complexity of situations). As in the current implementation of Automated Driving Functions (ADFs) in extra-urban roads, the vehicle simply asks Eva to come back into the control loop, thus performing a take-over-request (TOR). If she does not respond within a given time, the

vehicle actuates a minimum risk maneuver (MRM), stopping in the emergency lane (if any).
So, to sum up, the scenario consists in entering the roundabout, while the vehicle is in Automated Mode, but – due to technical limits – the vehicle cannot perform the roundabout (the manouver wouldn't be safe enough).
The expected consequences can be from the driver's and from the safety points of view. In the former, the driver can have frustration, reduced trust, poor acceptance (due to the continuous TORs); for the latter, there can be an "unobservable" car behavior: the vehicle stops unexpectedly in the road (when driver is not responding), or – if the driver is surprised by the request, for example – s/he can take the wrong action (safety concern).

2.1.2 TeamMate Scenario

In the TeamMate (TM) scenario, the vehicle asks Eva for a cooperation that can be both in perception and in action. In particular, the driver observes if the roundabout is safe, checking the environment. Then, the expected behavior (Scenario resolution) consists in a sharing control, where the machine-agent (the vehicle) and the human-agent (Eva) decide to share the responsibility of the driving task as a whole. In this case (roundabout), the automation takes the longitudinal control, while Eva the lateral control (cooperation in action).
In addition, after approaching the roundabout, when the vehicle has to start again, the decision is left to the human driver, so Eva decides when it is the best time to enter (cooperation in perception). After that, the manouver is performed in sharing mode (as described above). Of course, this is all true if Eva is in an attentive mode (i.e. she is not distracted); in case she is, the automation adopts specific strategies to get her back into the control loop. If this operation fails, the vehicle has to perform a MRM (as described in the previous section).
The crucial enablers that will increase the abilities of the car and its cooperation with the driver in this case are: Multimodel TeamMate HMI, DMS, online risk assessment, planning and execution of safe manouver.

2.2 Baseline car equipments and abilities

The CRF demonstrator has been mainly described in deliverable D5.3 "D5.3 – TeamMate Car Demonstrator after 2nd Cycle". Hereafter, just the main components are summerised and illustrated.

Figure 1: CRF prototype vehicle.

The Figure 1 shows the prototype vehicle on which the BL car is implemented. Which is the same Jeep Renegade, as described in delieverable D5.3.

2.2.1 Hardware architecture

The following figure (Figure 2) shows the electric components:

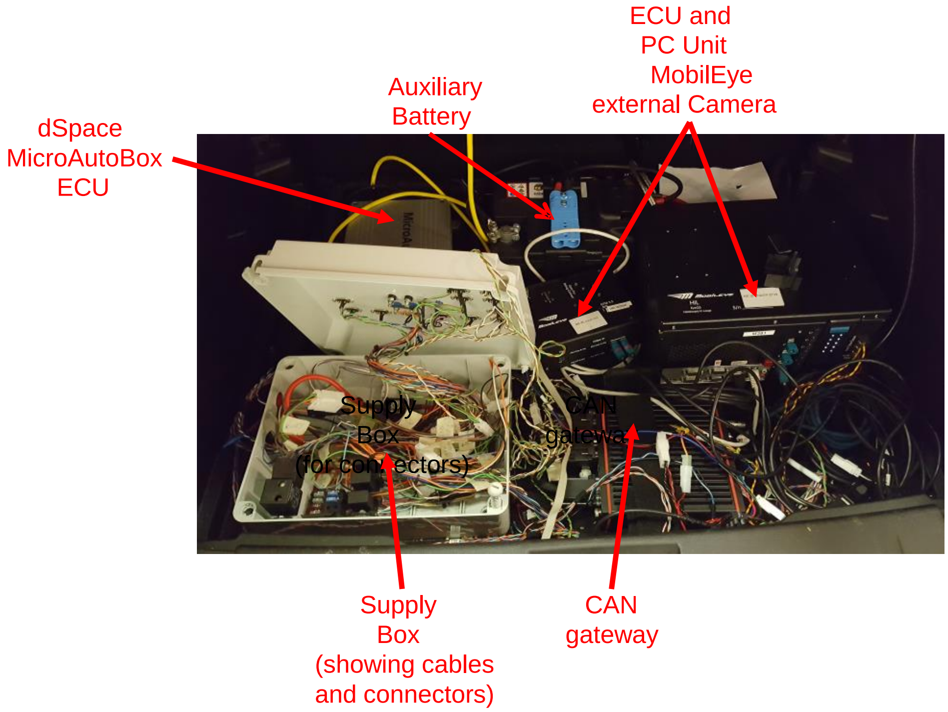


Figure 2: the car trunk, with the HW and electronic part of the CRF vehicle.

The location of sensors is illustrated in Figure 3:

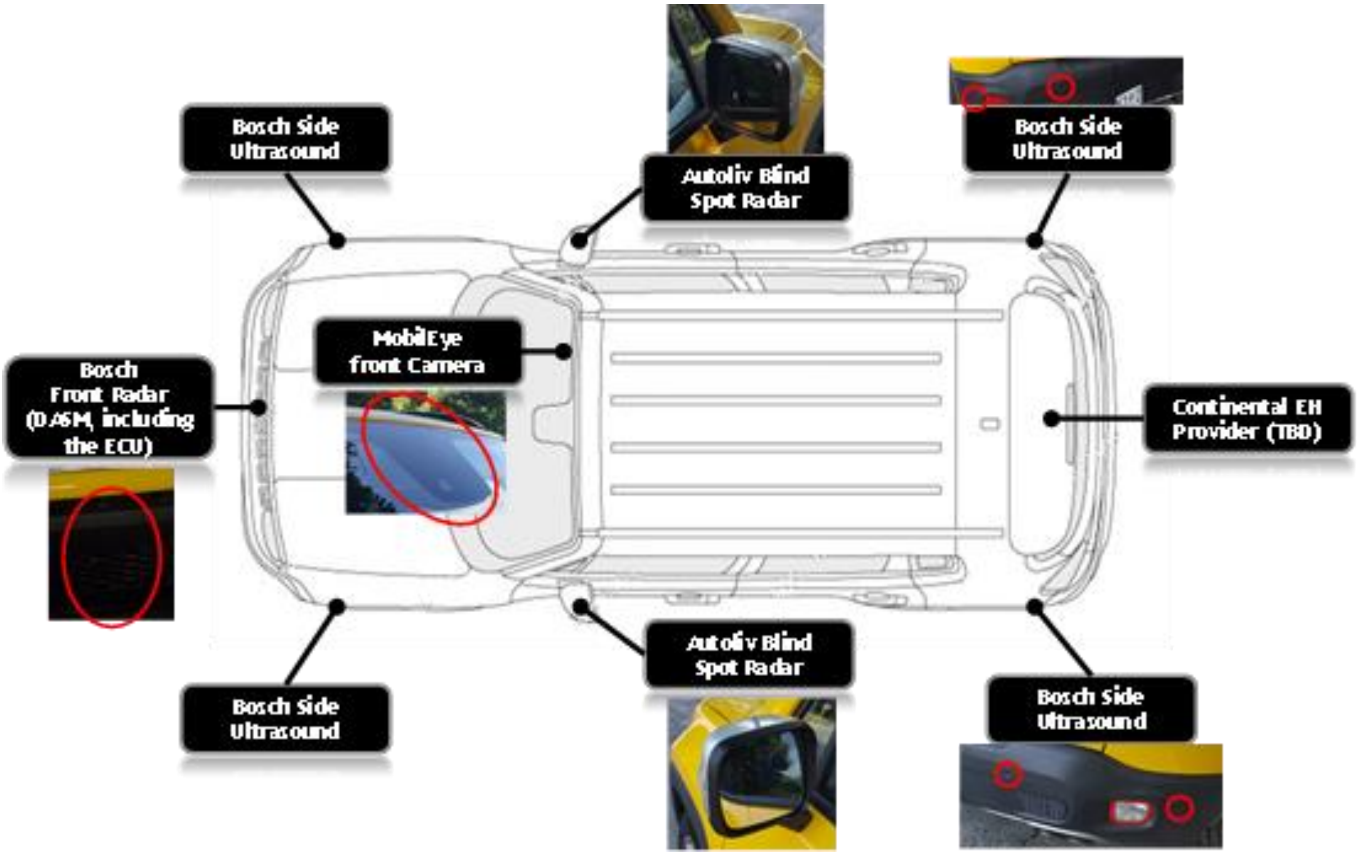


Figure 3: location of sensors in CRF prototype vehicle.

It is worth noting that the sensors are the same used for implementing the TM car, since the relevant differences are in the use of the HMI enablers, the development of advance interaction strategies (the cooperation modes previously illustrated) and the presence of the Driver Monitoring System, to classify the state of Eva (i.e. distracted or not).

2.2.2 Software architecture

The general SW architecture for the BL car of CRF is illustrated in Figure 4 :

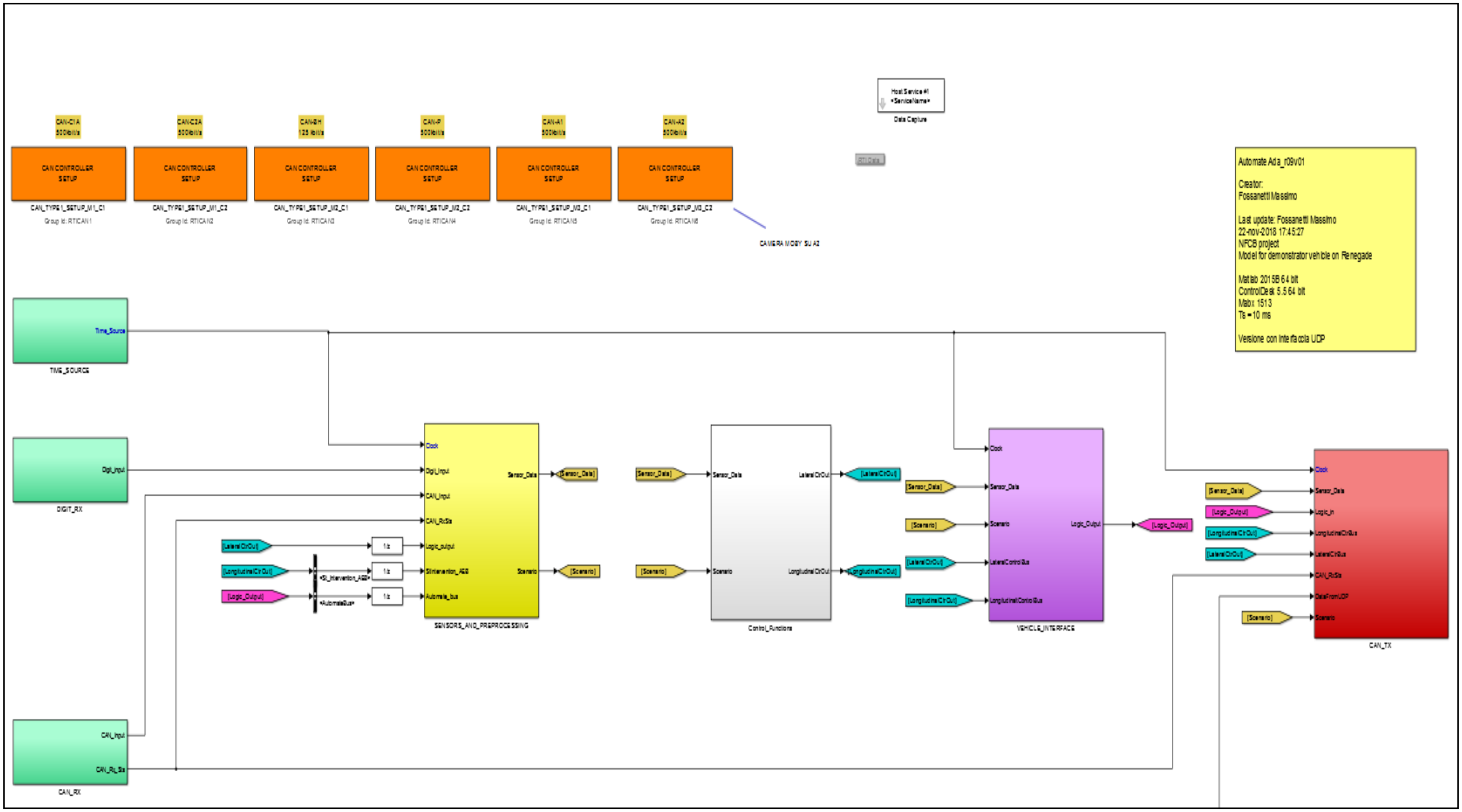


Figure 4: SW architecture for CRF baseline car.

In the Figure 4, the main blocks of the CRF baseline car are sketched. In the GREEN and YELLOW modules, the inputs from sensors are pre-processed and fused to obtain the reconstruction of the environment. The GREY block is about the high-level control algorithms of the vehicle, while the VIOLET one is for the basic HMI presented on the vehicle. Finally, the RED module defines the output signals for the actuators (low-level control).

The following two figures (Figure 5 and Figure 6) show the details of the SW architecture for longitudinal and lateral control, respectively.

All these modules are implemented using the toolchain MATLAB, SIMULINK and STATEFLOW.

Finally, a basic HMI is also provided, in the panel instrument of the vehicle, to inform the driver about possible TORs.

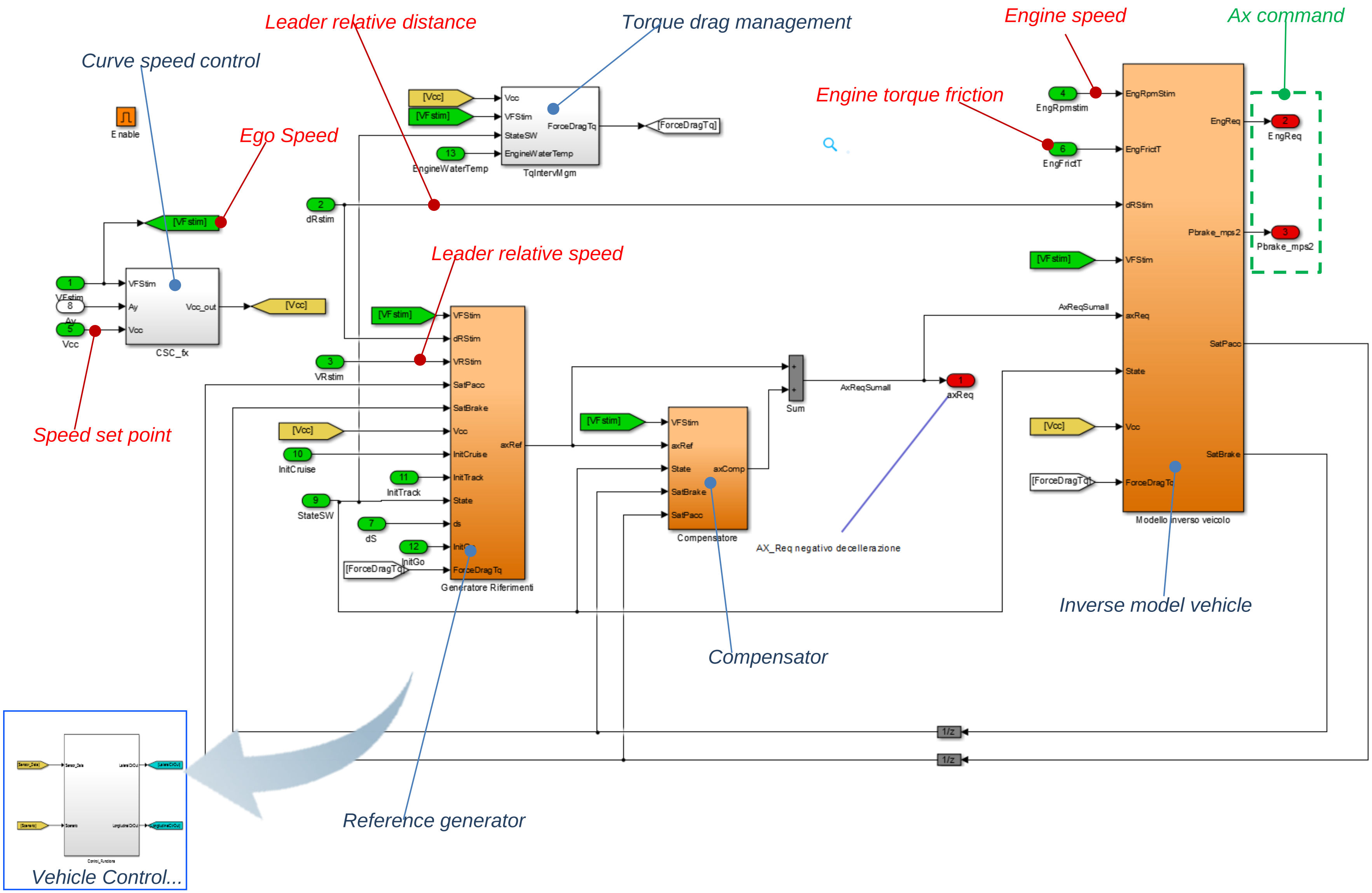
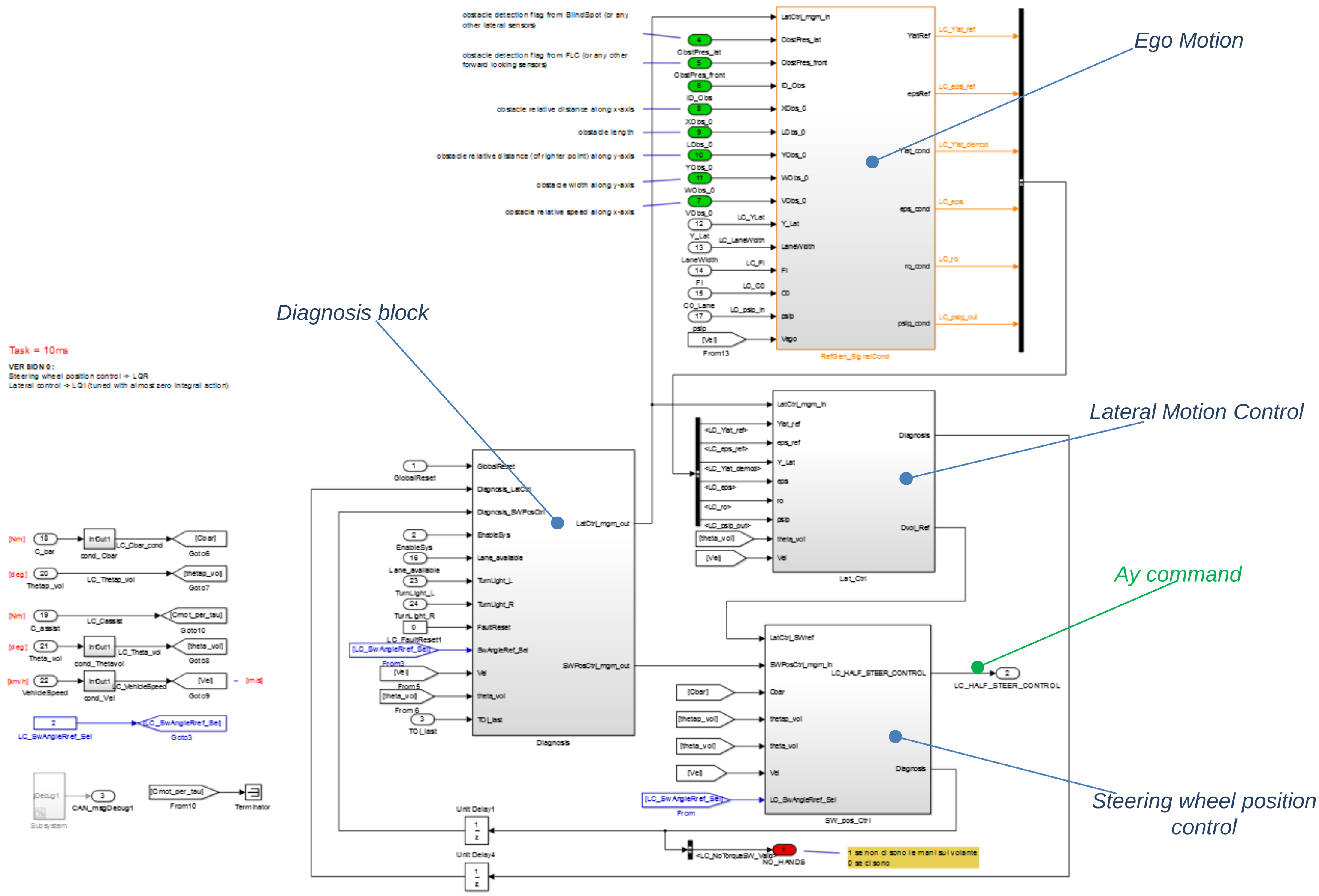

Leader relative distance
Torque drag management
Engine speed
Ax command
Curve speed control
Engine torque friction
Ego Speed
Leader relative speed
Speed set point
Compensator
Inverse model vehicle
Reference generator
Vehicle Control...
AX_Req negativo decellerazione
CSC_fx
TqIntervMgm
Generatore Riferimenti
Compensatore
Modello inverso veicolo
Sum
AxReqSumall
axReq
EngReq
Pbrake_mps2
EngRpmstim
EngFrictT
dRstim
VRstim
VFstim
Ay
Vcc
Enable
InitCruise
InitTrack
StateSW
dS
InitGo
EngineWaterTemp
[ForceDragTq]
[VFstim]
[Vcc]
1/z

Figure 5: longitudinal control SW architectural scheme.


Ego Motion
Diagnosis block
Lateral Motion Control
Ay command
Steering wheel position control
Task = 10ms
VERSION 0:
Steering wheel position control -> LQR
Lateral control -> LQI (tuned with almost zero integral action)
RefGen_SignalCond
Diagnosis
Lat_Ctrl
SW_pos_Ctrl
LC_HALF_STEER_CONTROL
Unit Delay1
Unit Delay4

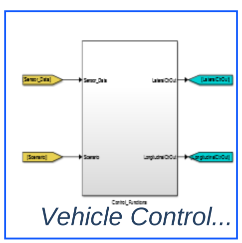

Vehicle Control...

Figure 6: lateral control SW architectural scheme.

3 ULM baseline CAR

3.1 Peter Scenario

The car is driving in automated mode on a rural road. It approaches towards a truck that blocks the sensor view.

3.1.1 Baseline scenario

The system cannot guarantee that overtaking will be safe since it cannot make justified assumptions about the opposite lane. Therefore, the car has drive at low speed behind the leading vehicle which increases the travel time and frustrates the driver.

3.1.2 Peter Scenario

Since the leading vehicle drives very slow the car's intention recognition supposes that Peter wants the system to overtake. This implies a system boundary, because of the blocked sensor view due to the leading vehicle the system cannot guarantee that overtaking might be safe at all. Therefore, it requests for support of the driver and asks Peter if the opposite lane is free and hence if overtaking will be safe. If there is not oncoming vehicle, the automation triggers overtaking.

3.2 Baseline car equipments and abilities

Figure 7 show a picture of the Ulm demonstrator.

Figure 7 : ULM CAR

The Vehicle is a Mercedes Benz E-class that is extended for additional sensors and was manipulated in a way that actuators can be controlled by the algorithms running on the onboard systems.

The vehicle is equipped with 2 cameras for front and rear and 2 radars for front and rear as well. Four rotating lasers on the top of the vehicle care for circumferential view. A lidar at the nozzle percepts environmental information in front of the vehicle. Figure 8 shows the field of view for each sensor type.

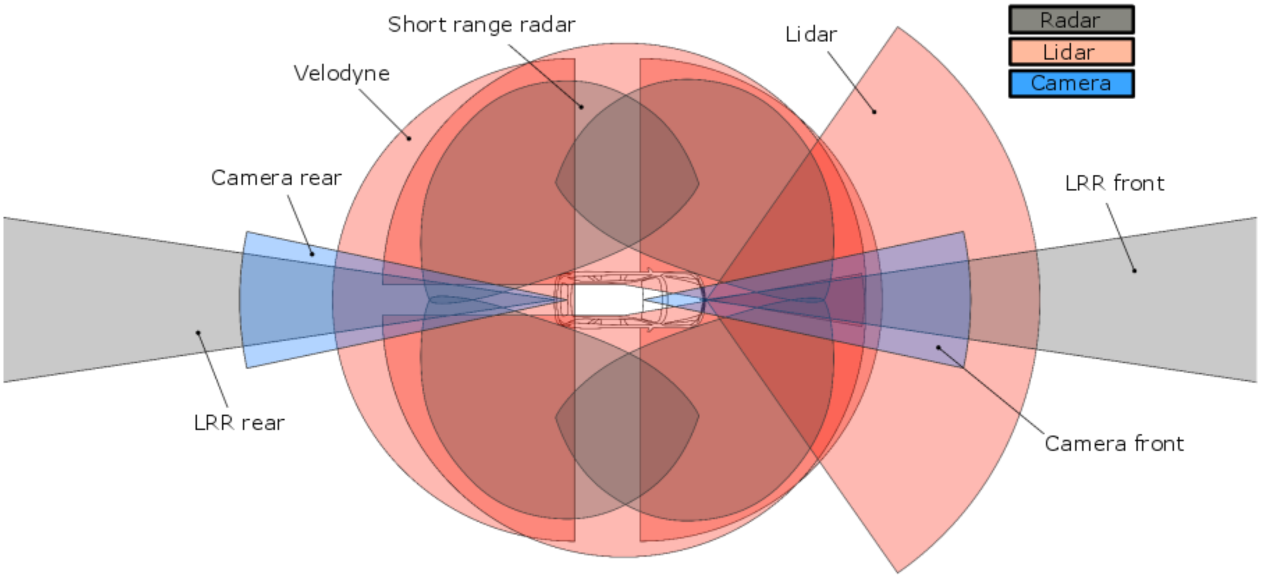


Figure 8: ULM CAR sensors field of view

In order to process the sensors inputs the vehicle has in general 3 onboard computer systems that are shown in Figure 9.

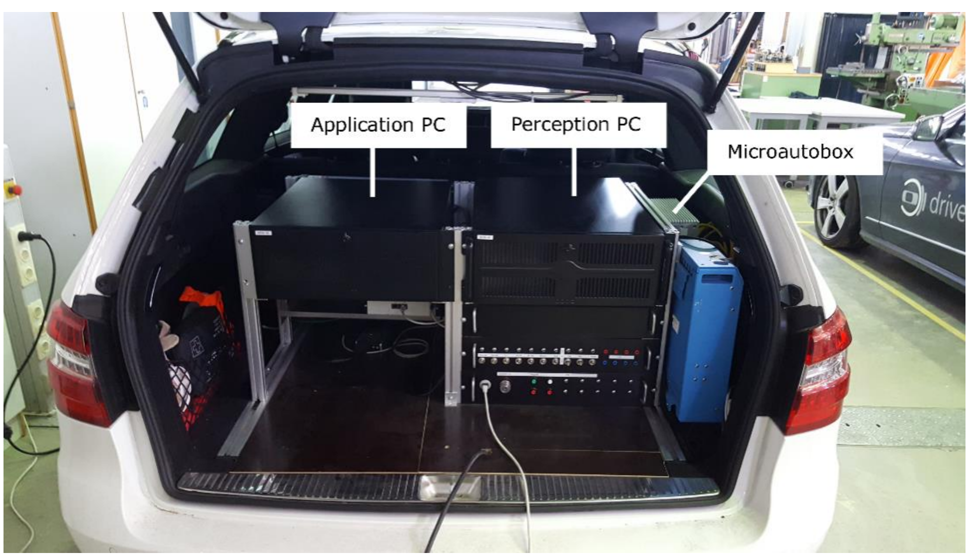


Figure 9: PC's and ECUs for the ULM Car

The perception PC processes the sensorial data, performs tracking algorithms and creates a dynamic model of the environment. Software running on the application PC is closer to the actuators, algorithms like the one for trajectory planning are running there. The Microautobox runs the security system of the vehicle and control algorithms.

All PCs are connected with the vehicles CAN bus in order to be able to gather all information needed.

3.2.1 Hardware architecture

The hardware architecture is as follows. The sensors send recorded data to the perception PC. Processed results are then transmitted to the application PC where data for direct control of actuators is computed. Perception and application PC always need to communicate with the Microautobox where the security system, the longitudinal and lateral controller as well as further functionality such as e.g. vehicle monitoring etc. are running. The Microautobox forwards results such as e.g. the trajectory directly to vehicle controller. All PCs always display their own results as well as the vehicle state on the display that can directly be viewed by the driver.

Figure 10 shows a diagram of the architecture.

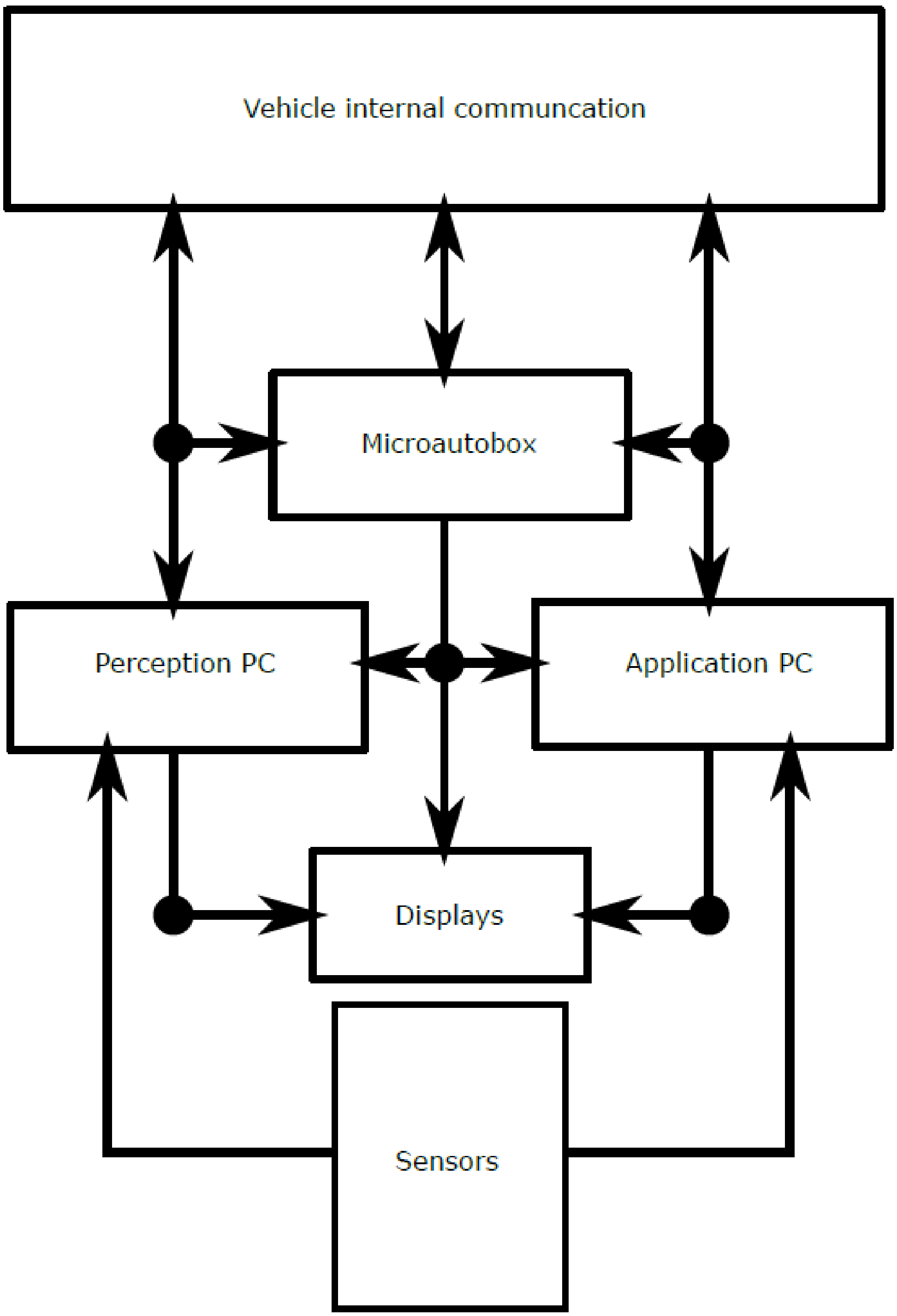


Figure 10: general hardware architecture

3.2.2 Software architecture

The software architecture of the vehicle is shown in Figure 11.

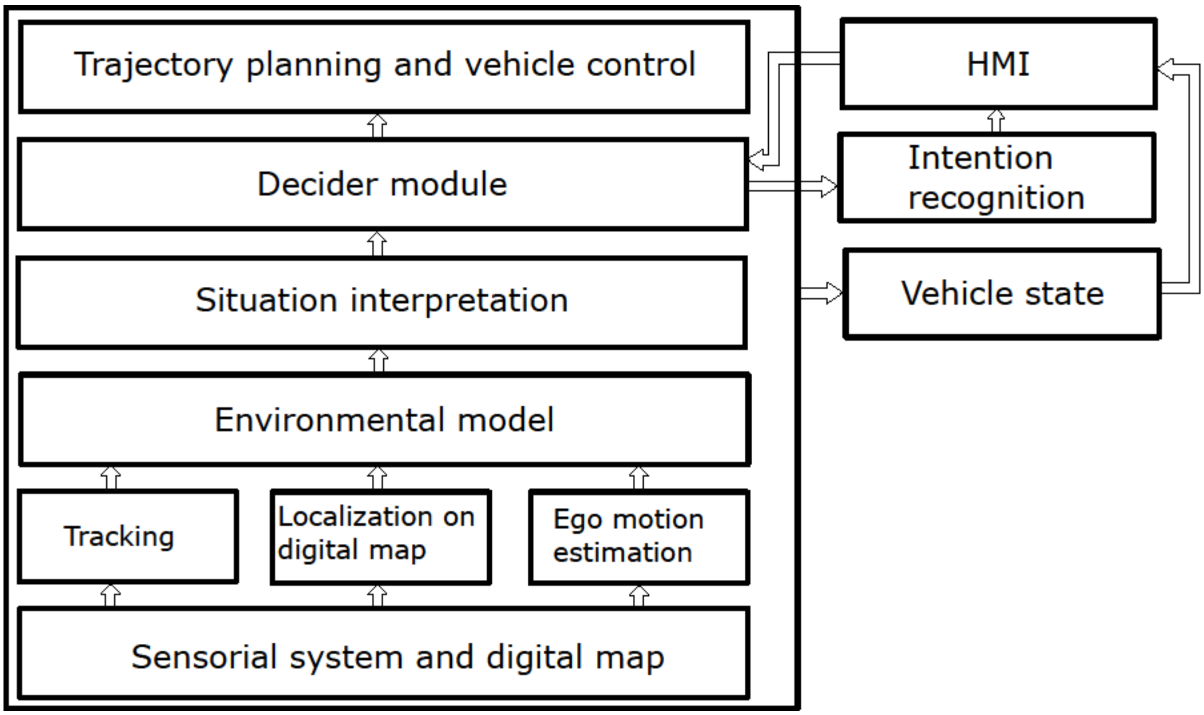


Figure 11 : ULM car software architecture

At first the environment is percepted using the sensorial sensor equipment described previously, also a digital map of the route intended to drive on is recorded. Subsequently, further traffic participants are tracked, the position of the ego vehicle is localized on the digital map and the ego motion is estimated as well. From these data an environmental model is created. This model is forwarded to the situation interpretation, where semantic information is extracted from the environmental model. The decider module determines the maneuver for which a trajectory is calculated in the trajectory planner.

The HMI is no part of the baseline car, but will be a component of the teammate arichtecture. It receives data of the vehicle state and data of the intention recognition module as well. Via the HMI the driver is able to communicate actions to the vehicle such as releasing the overtaking maneuver as intended within the Peter scenario.

4 VED baseline CAR

4.1 Martha Scenario

- **Baseline scenario**

The TeamMate car is driving in an extra-urban road in Automated Mode. Martha receives important text messages and is distracted because she has to answer and does not pay much attention to the road. Martha is not aware in advance of the roadworks in the baseline car and she has to take over control when the car reaches its limites and only has few seconds.

This scenario shows some risky situations and limitations. Indeed, as designed the VED baseline is not able:

- To detect the distraction of Martha during her answering to the text message and thus is not able to warn her to keep attention nor take over control.
- To detect the roadworks ahead via sensors (maximum 200 m of field of view) since the V2X of the baseline car is not used.

4.2 Baseline car equipments and functionalities

4.2.1 Baseline vehicle overview

The VED baseline is derivated from a production vehicle called "Citroën C4 Picasso" with 7 seats. The vehicle is delivered as a robotized platform to VED, which allows the access to vehicle organs via the dedicated ECUs in order to control its lateral and longitudinal movements. Originally the vehicle does not include any sensors nor joystick. The subsequent tranformations of the vehicle to build an automated vehicle were carried out later on by VED integration and experementation team.

Figure 12 : Original Baseline Vehicle "C4 Picasso"

4.2.2 Vehicle cockpit

The cockpit of the robotic vehicle has been changed and designed to better meet the needs of an automated vehicle baseline. In the pictures below (Figure 13, Figure 14), we can notice two main changes:

1. The dashboard is equipped with an additional screen just in front of the driver. This device can be used to display specific information for the automated mode for the baseline.

2. The steering wheel has also been changed in order to improve the visibility of the driver so he can access easily the information displayed in the added front screen.

Figure 13. Production Vehicle Cockpit

Figure 14. Cockpit of the Baseline Vehicle

4.2.3 Central console

The central console contains the sequential gear lever, the emergency stop button (can be activated in case of failure), the remote control of the CAN recorder and the yellow cable that allows ethernet communication with the supervisor (MABX). The central storage box has been equipped with 2 buttons: one to activate / deactivate accelerator pedal lure; the other to activate / deactivate gear box lure.

Figure 15. Central Console

Figure 16. Central Storage Box

Two boxes have been integrated in the glovebox of the front passenger seat, as shown in the picture below:

- Switch LVDS box: it allows to switch the video signal of the tactical central screen (DGT 7") by either broadcasting the serial HMI of the vehicle or the prototype HMI via the openscreen box in the trunk.
- Accelerator lure pedal and speed gear box

Figure 17. GloveBox of the front passenger seat

4.2.4 Underhood

In the engine comportment, some modifications have been made. A C-Sample ESP has been integrated, which allows to send braking orders by CAN (with some deceleration limits). A circuit breaker has also been installed that allows to cut the link between the front and the rear battery.

Figure 18. Underhood of the baseline vehicle

4.2.5 Trunk

The trunk is designed to accommodate different control and power boxes. Different components are shown in the table below. An additional 12V battery is installed. There is a general power management control box (Figure10) and additional switches related to PGA (Figure 15).

4.2.6 The PGA

Figure 10 shows the PGA, which allows to distribute permanent power supplies to proto-organs, manage power supplies via a dedicated CAN, make analog acquisitions 0-11V (to read a press button for example) and return info on the CAN bus. This PGA incorporates a battery coupler and a circuit breaker.

Figure 19. Additional power management bloc

Figure 20. Power Management Control Box

4.2.6.1 CAN BOX

CAN Box in the figure below (Figure 11), shows the different can buses that can be accessed.

Figure 21. Can Box of the Baseline Vehicle

4.2.7 Hardware architecture of demonstrator

The baseline vehicle is built from a robotic platform described above has been transformed to build a basic automated vehicle by integrating different components like sensors, antennas, and additional calculators (described below). Enablers of the project are integrated in the car but they are not used for the baseline demonstrator scenario. The vehicle allows the standard manual driving and the self-driving mode. In manual driving mode, the performance of the vehicle remains compatible with a standard vehicle. In self-driving mode, the vehicle relies on its sensors and cartography to make decisions and send control commands to vehicle organs.

4.2.7.1 Overview of the external equipments

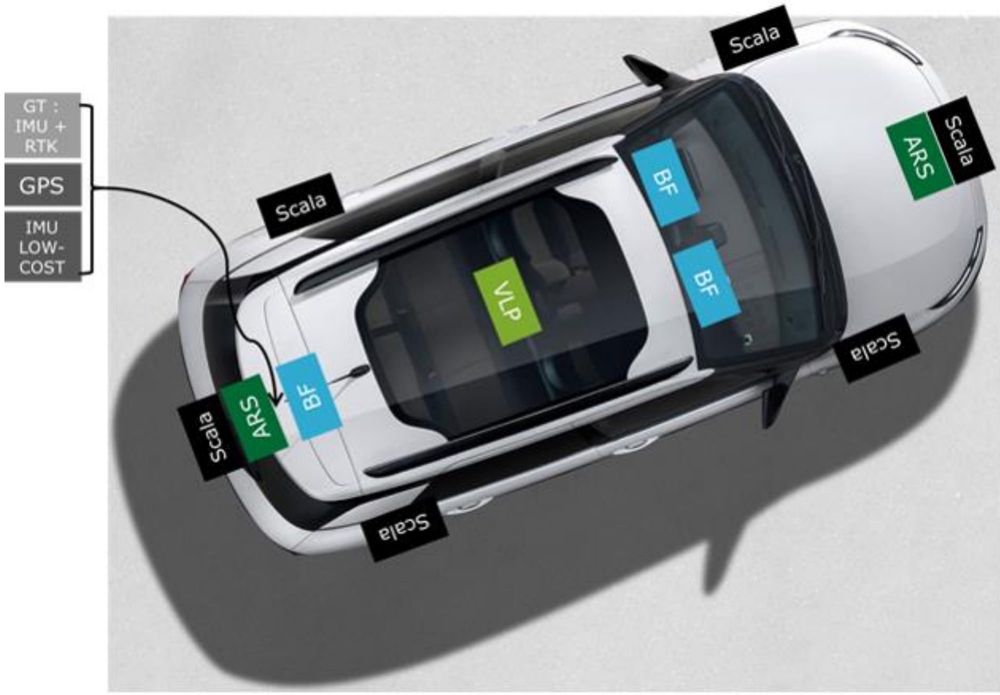


Figure 22. Top View of the C4 Vehicle & Integrated Sensors

The vehicle is equipped with the following external components:

- Valeo Scala LIDARs ensuring 360° of coverage, with a minimization of blind spots. The vehicle is equipped with six Valeo Scala lidars. Three lidars are placed on the front bumper and three others on the rear bumper.

- 2 Radars Continental ARS 408, one at the front and one in the rear of the vehicle.

- 2 cameras at the front and 2 in the rear allowing both mono and stereo vision for ground detection and lane marking detection.
- A Velodyne VLP 16 for HD-Maps building.

- Atlans IMU for accurate positioning.

- Spetentrio RTK (real time kinematics) GPS.
- Blackfly front stero cameras (x2)
- Blackfly rear camera

Figure 23. Front Cameras Installation

Figure 24. Rear Camera Installation

- 1 antena GNSS trimble
- 2 antenas 3G/4G

Figure 25. Sensors Integrtaion on front & rear bumper

The vehicle is also equipped with internal components and systems that are embedded in the trunk of the vehicle:

- Inertial motion units (Figures 26, 27 and 28)

Figure 26. SBG Ellipse – Low cost inertial unit

Figure 27. SBG Apogée - middle cost inertal unit

Figure 28. Atlans-C – upmarket central unit (IXBUE)

- 1 SBG Ellipse - low cost inertial unit (Figure 26).
- 1 SBG Apogée – middle cost inertial unit (Figure 27).
- 1 IXBLUE upmarket central unit for ground trouth and validation (Figure 28).

The inertial units are fixed in the central shelf near the Y0 reference of the vehicle (center of the rear axle)

- 2 Nuvo industrial computers: one for the perception and ne for the pathplanning and decision maling called supervision In the architecture of the baseline.

- 1 THD Box for GNSS RTK+GSM reception, and analysis for GPS position correction.

- 2 MotoHawk Engine Control Modules

- CAN routers

- 1 alimentation bloc (relay fuse box & additional battery)

4.2.8 Software architecture

Based on the sensors presented in section 4.2.1, we derived the architecture described in the figure bellow. It is a layered architecture that goes from the sensors to the decision making and control.

The main modules that composing this architecture (Figure 28) are the following:

- Two Laser based obstacle detection algorithms running in real time (25hz), they are able to provide data from the surrounding obstacles and their dynamic variables (speed, acceleration ...),
- A radar-based filtering algorithm,
- A probabilistic fusion module that aims to agregate the data from the obstacle detection and predict their evolution in time,
- A camera-based lane marking algorithm,
- A data association module that associate each observed algorithm to its lane,
- A supervision and decision-making algorithm: this module is connected to all the previous modules and is able to synthetize the data at a certain level of abstraction and give a decision, this decision is in term of path planned and control variables (acceleration, bracking, emergency braking …). In addition, it has the ability to check the pertinence of the data for safety reasons.
- An informational HMI is installed to show the route and the surrounding environment.

All the modules are developed in C++ and are integrated in an RTMAP (Intempora) diagram as shown in the Figure 29.

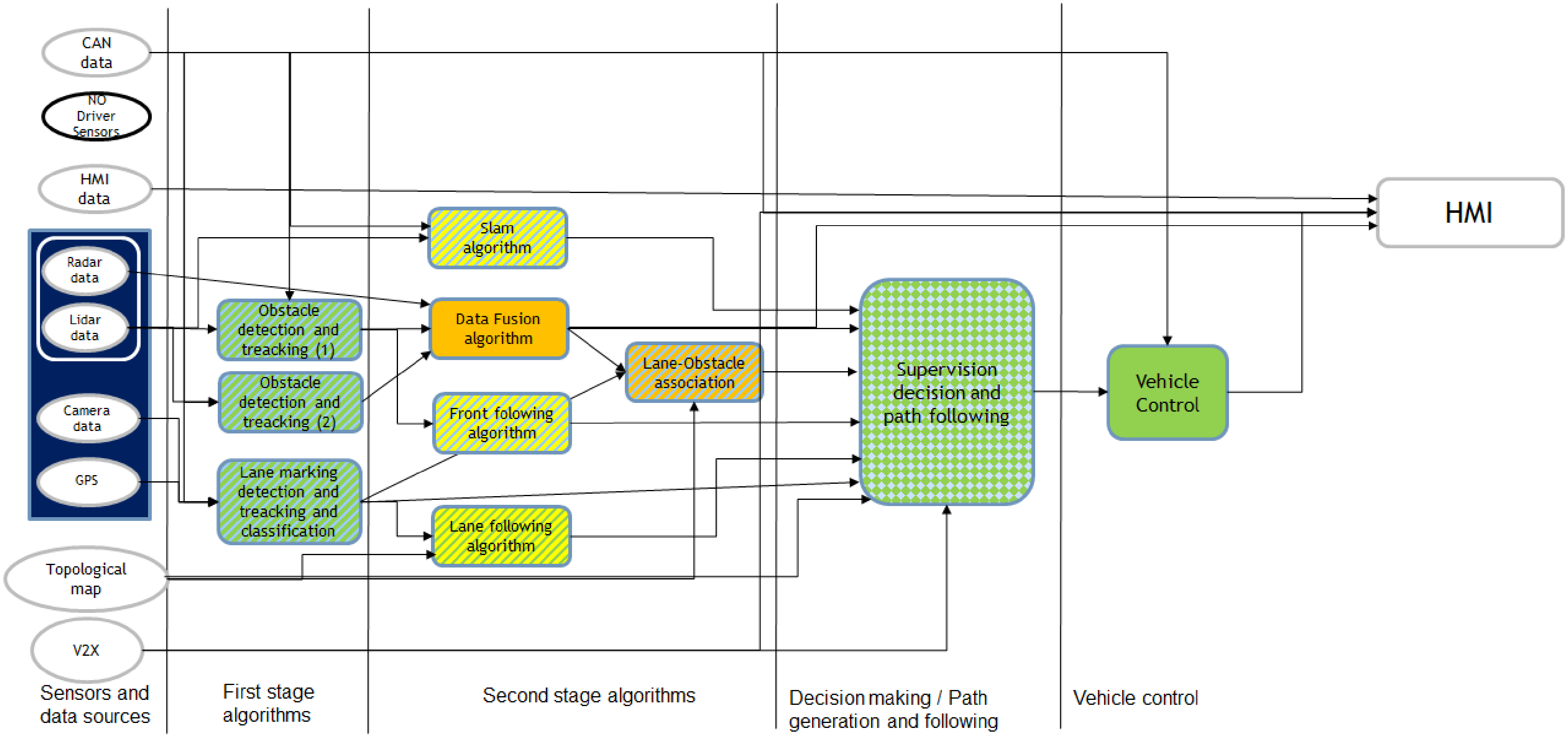


Figure 15: VED baseline architecture.

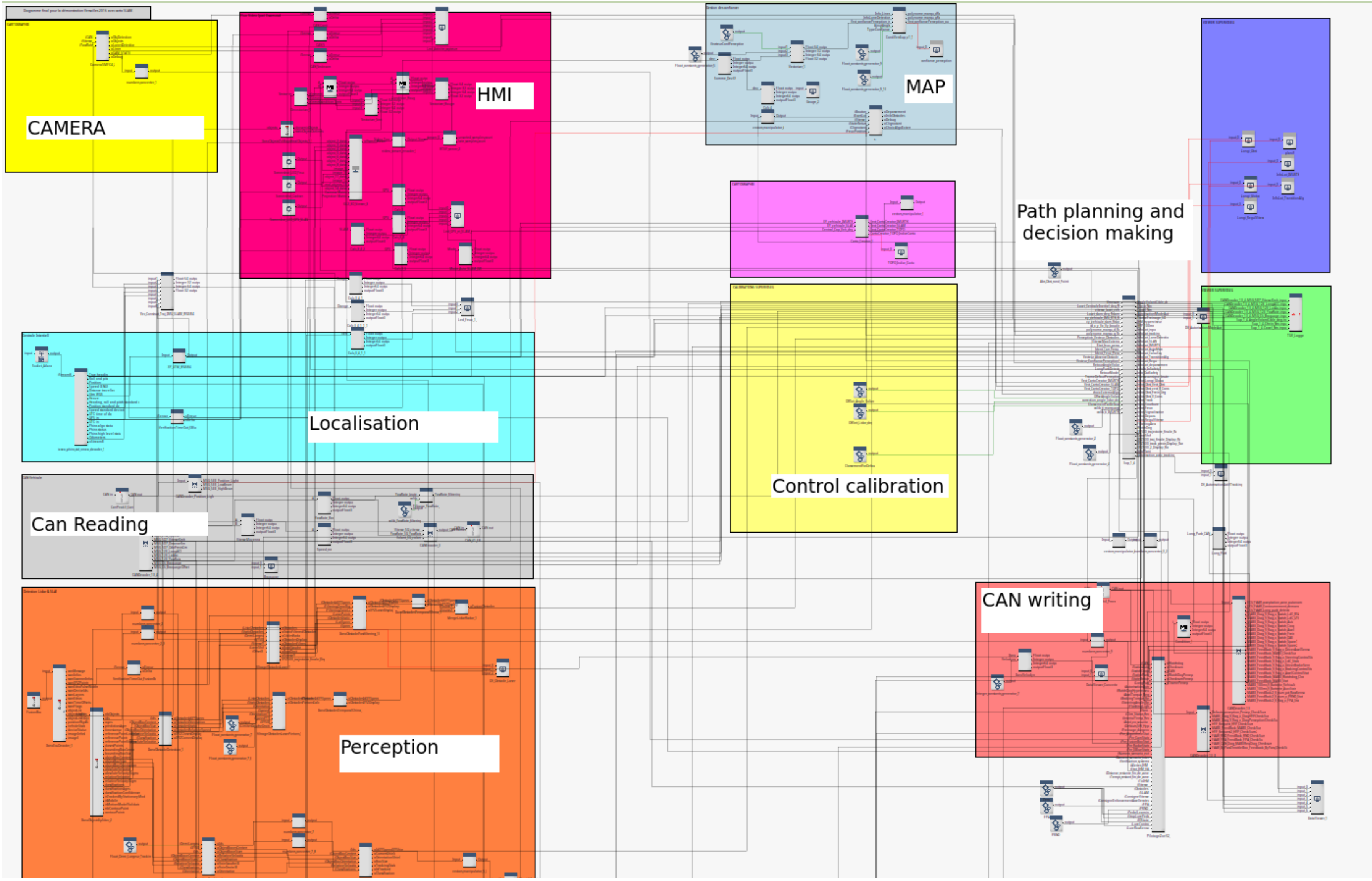

CAMERA
HMI
MAP
Path planning and decision making
Localisation
Control calibration
Can Reading
CAN writing
Perception

Figure 29 : Overall integration of the VED baseline

5 Conclusion

This document describes the three baseline cars of the project AUTOMATE.

- The CRF car that don’t have the capacity of roundabout passing and thus have to ask the driver to take over in order to pass the round about.
- The ULM baseline car that is dedicated to rural driving and that has no ability to overtake, there are two possibilities: either the driver take over and overtake, or the car stays in autonomous mode but drives very slowly (behind a slow tractor for example).
- The VED car that do not have connectivity with the infrastructure to get information about closed lanes because of roadworks and that is not able to monitor the driver in order to detect its distraction and make her aware about risky situations.

This document highlights the different equipments of each baseline car and its abilities. These equipments (hardware and software) are showed in their respective architecture.