Fortuna: Presenting the 5G-Connected Automated Vehicle Prototype of the Project PROVIDENTIA

Preprint · November 2019

DOI: 10.13140/RG.2.2.24402.91842

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Abstract— **Fortuna is the connected automated vehicle prototype built by the fortiss research institute in the course of the project PROVIDENTIA. In the project, an intelligent infrastructure prototype is created along a 2.5 km stretch on the highway A9 north of the city of Munich, Germany.**

This paper presents the vehicle Fortuna and illustrates the requirements which led to design decisions for the vehicle modifications. A detailed description of these modifications will help researchers to design their prototype vehicles in future. Fortuna is equipped with a sensor set comprising lidars, radars, cameras and a reference localization system. A special feature is its 5G cellular communication interface connecting it to the PROVIDENTIA intelligent infrastructure prototype.

I. Introduction

Automated vehicles rely on sensors through which they perceive the environment. These sensors have a limited sensor range and Field of View (FOV), which is additionally reduced due to occlusions of other vehicles in the line of sight to a possible obstacle or hazard.

The project PROVIDENTIA [1, 2] aims to overcome this shortcoming by enhancing the FOV of automated vehicles. This is attained by using data from sensors placed on road side infrastructure and communicating this additional information to the vehicle. Infrastructure sensors can be placed on poles and bridges high above the road surface, such that less obstructions due to other vehicles limit the FOV. These sensors simultaneously monitor the traffic on the highway and feed the sensor information into data fusion units. There, multi-sensor data-fusion algorithms calculate a digital twin containing states and classes of all traffic participants in real-time. The digital twin will also be able to incorporate information about the environmental perception of automated vehicles (showcased with Fortuna) and can be transmitted back to the vehicle in order to enhance the vehicle's field of view.

The additional environment information can support the behavioral planning of automated vehicles in order to render decisions more thoughtful. This helps to increase traffic flow and safety while reducing energy consumption. For connected manual vehicles, warnings created by the infrastructure may be sent to the driver to support various use cases, like Forward Collision Warning, Lane Change Warning, Emergency Brake Warning, Approaching Emergency Vehicle Warning or Roadworks Warning.

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Fig. 1. Fortuna: fortiss' modified Passat GTE with extended sensors and hardware. It is equipped with a prototypical 5G solution to communicate with the intelligent infrastructure of the PROVIDENTIA test field.

These use cases are enabled by communication through wireless networks, known under the term Vehicle-to-Everything (V2X) communication, and serve as prominent examples for a Cooperative Intelligent Transportation System (C-ITS). The concept of C-ITS aims to connect every road user, i.e. vehicles, pedestrians, cyclists etc., and promises to increase road safety and road traffic efficiency while rendering traveling more convenient. Two alternative technologies are developed to facilitate V2X services, namely:

1) IEEE802.11p, named Dedicated Short-Range Communications (DSRC) and
2) 3GPP V2X, commonly termed as Cellular Vehicle-to-Everything (C-V2X), which builds on Fourth Generation of mobile radio - LTE (4G) and Fifth Generation of mobile radio (5G) system.

As PROVIDENTIA mainly relies on backend systems, it is essential to provide Vehicle-to-Network (V2N) communication to access these services. Since from the above two technologies only 3GPP mobile communication is built upon a network infrastructure, 3GPP V2X is the preferred V2X solution in this context. 5G is on the verge of introducing mobile communication services capable of operating road safety applications with stringent requirements on high reliability and low latency.

In this paper, we present Fortuna, the research vehicle of the fortiss Institute, which was built for the PROVIDENTIA project. Fortuna is named by a play on words between "fortiss 1" and the roman goddess "Fortuna", also named

"Automatia" in antiquity, while the PROVIDENTIA project is named after "Providentia", the divine personification of the ability to foresee in ancient Roman religion. The paper presentation puts an emphasis on project requirements to understand the design decisions for Fortuna. An important aspect is the integration of V2X communication, which enables connection of Fortuna with our infrastructure prototype.

The remainder of this paper is organized as follows. Section II will give an overview of publications on other connected automated research vehicles. We then list the requirements in Section III, leading to the design decisions in Section IV. This will help other researchers when building new research prototypes in future, together with Section V, which gives a detailed description of Fortunas hardware setup. Section VI gives a conclusion and an outlook on future work.

II. Related Work

Many automated vehicle prototypes were presented since the 1980's, when the "VaMoRs" vehicle was probably the first of its kind, developed at the Universitaet der Bundeswehr Muenchen [3]. It would be out of scope to mention them all, but we want to refer to [4] for a more detailed overview on automated vehicles in general. For this review, we want to limit the scope on *connected* automated vehicles published by research institutions.

In 1997, an early demonstration of a cooperative platoon consisting of up to eight vehicles was presented in the scope of the Demo 97 project in San Diego, CA [5]. In the Demo 2000 project [6], a cooperative driving system for platooning with Vehicle-to-Vehicle (V2V) communication was showcased. Trucks in the platoon utilized DSRC for the V2V communication, which operated in the 5.8 GHz frequency band.

In 2006, in the scope of the PATH project, several V2X-based applications were investigated. This included a cooperative Forward Collision Warning (FCW) using standard home-use IEEE 802.11b WiFi technology and a Vehicle Infrastructure Integration (VII) test bed in California. Use cases were presented in [7]. They included "Vehicles as Traffic Probes", which were sending their location data to Road Side Units (RSUs), but they did not consider sensors aiming at detecting vehicles in real-time.

In 2011 and 2016, two major events were held to push the development and application of V2X communication forward: The Grand Cooperative Driving Challenge (GCDC) 2011 [8] and 2016 [9]. For both events, vehicles were equipped with V2X communication modules based on the IEEE 802.11p wireless standard. The 2011 Challenge was to demonstrate basic collaborative platooning (forming and maintaining a platoon) on urban and highway scenarios, while in 2016, more complicated platooning scenarios had to be realized. Various connected automated vehicles were taking part in the Challenge; some of these we will describe in the following.

In the 2011 Challenge, team AnnieWAY [10] from Karlsruhe Institute of Technology (KIT) participated with a modified VW Passat, which they already used for the 2007 DARPA Urban Challenge [11]. They described that they were facing difficulties to realize the cooperative highway driving tasks when other teams were sending noisy position estimates, especially when driving below highway bridges. They concluded "that certified high-quality GPS/INS sensors are required to enable safe operation." Regarding V2X communication through IEEE 802.11p, they reported stable communication for ranges up to roughly 800 m. Also in 2011, Kianfar *et al.* from Chalmers presented their vehicle prototype ChalmersU [12], and Lidstrom *et al.* [13] presented the vehicle with which the Halmstad University team finished second in the 2011 GCDC. Both were modified Volvo S60s.

In the GCDC 2016, KIT participated with BerthaOne [14], a retrofitted Mercedes E-Class. A team from Chalmers started again with a modernized version of ChalmersU [15].

All the aforementioned vehicles participating in the GCDC challenges were equipped with an automotive compliant real-time computer, most mentioned a dSPACE MircoAutoBox in different versions. Many reported to use Robot Operating System (ROS) as middle-ware.

Looking at other publications, [16] presents the research vehicle platform developed at Carnegie Mellon University, which is equipped with a DSRC modem for V2X communication. They showcased improved intersection handling with traffic light information accessed by Vehicle-to-Infrastructure (V2V). Gnatzig *et al.* [17] presented the realization of Teleoperated Support (TeSo) via Third Generation of mobile radio - UMTS (3G) communication in 2013. Video images were transmitted to an operator interface, which enabled direct control of the vehicle.

Although it was not a connected vehicle, we want to mention that fortiss already presented a vehicle prototype demonstrating a fail operational architecture for automated vehicles in 2015 [4]. Due to the use of prototypical hardware for safety critical parts, like a steer-by-wire system without mechanical fall-back and a novel brake system, its use was restricted to closed proving grounds.

Burch *et al.* [18] demonstrated stable control and tracking of a vehicle driving on a path planned by infrastructure-enabled autonomy, only relying on roadside sensors.

Looking at connected vehicles utilizing 5G, Cao *et al.* [19] presented a 5G V2X testbed for cooperated automated driving in 2016. Several research projects were established and industry field trials were conducted to investigate automated driving enabled by C-V2X. The Nordic Way Project [20] investigates a hybrid approach where DSRC and C-V2X are dually supported to offer V2X services even to vehicles driving in rural environments. 5G Connected Mobility [21] elaborates on 5G for C-ITS. This project established a prototype test network operating in the 700 MHz frequency band to provide 5G connectivity to interested stakeholders for testing V2X applications. 5G Automotive Association (5GAA) published a report [22] in 2018 comparing the performance of DSRC IEEE 802.11p with C-V2X based on 4G. According to the outcome of the report, C-V2X outperforms IEEE 802.11p in terms of communications range and reliability, even in scenarios where vehicles exhibit signal interference.

III. Requirements

In short, Fortuna aims to serve the following purpose in the project PROVIDENTIA:

- Investigate how sensory information of automated vehicles can be provided to the PROVIDENTIA infrastructure in real-time,
- exploit how additional information provided by the digital twin can improve automated driving functions and
- investigate how PROVIDENTIA-like intelligent infrastructure can support human drivers.

In more detail, it was designed to meet the following requirements:

1) Provide a *ground-truth regarding the position* of the vehicle in order to calibrate and verify the intelligent infrastructure prototype
2) Support the investigation of use cases as defined in 3GPP V2X [23] covering SAE Levels 0-5 [24]:
   - Provide a *human machine interface* to demonstrate V2X applications and perform user studies during SAE Level 0 to 2 operation as described in Wang *et al.* [25] (e.g. Emergency Stop Warning, Wrong Way Driving Warning)
   - Support information sharing for partial/ conditional automated driving: This use case is interpreted as SAE Level 2 and 3 driving. It requires to share local perception data (at least abstracted data) for cooperative perception and the vehicles driving intention for cooperative maneuvers. This can be enabled by *access to the production vehicle data*.
   - Support information sharing for high/full automated driving (SAE Levels 4-5): Requires to share *high resolution perception data* (e.g. camera, lidar) to support cooperative perception. Requires sharing detailed planned trajectories to realize cooperative maneuvers. This can be realized by additional sensors and software modules (perception, planning module).
   - Ability to support *advanced driving functions*, e.g. Cooperative Collision Avoidance (CoCA), Cooperative Lane Change (CLC) and TeSo.
3) Support for *network connectivity to enable V2N communication* with very low latency, enabling real-time applications based on the PROVIDENTIA system. Regarding SAE Levels 0 to 2, additional information obtained from external sensor sources mainly supports drivers by issuing warnings. The targeted recipient changes with SAE levels beyond 2 to that of automated vehicle functions. Requirements on communication service reliability and network availability increase accordingly. In addition to that, if vehicle sensor data are provided to the backend system, V2N communication service must satisfy demanding application-specific latency and throughput requirements. Evaluation of C-ITS applications shows that V2X service requirements differ significantly from those of common voice and data services. Therefore, investigation of service-specific network performance in terms of network coverage, data throughput, transmission latency and communication service reliability is an important objective of PROVIDENTIA.
4) *Ability to perform road tests* in the PROVIDENTIA test field. This implies a *permission for driving on public roads*. Following German legislation, this requires giving the safety driver the possibility to change back to unmodified production vehicle behavior. This requirement posed some restrictions, for example avoiding mounting side-viewing cameras at locations where airbags would need to be deactivated.

Out of scope of this project was the demonstration of a fail-safe or fail-operational vehicle system, capable to perform automated driving without a safety driver in place.

IV. Design decisions

Before we list the hardware components used in Fortuna, we want to give some insight into the considerations which enforced the selection of hardware.

1) Vehicle platform: Besides ecological considerations, Plug-in Hybrid Electric Vehicles (PHEVs) have the advantage of providing an extended integrated electric power supply with the possibility to recharge using the internal combustion engine. This extends the available development time on test tracks or in road traffic, when no external power supply for grid charging is available. This has proven to be a big advantage compared to full electric as well as vehicles with internal combustion engine only.

2) Localisation solution: A major requirement was to provide position ground-truth information. As already mentioned in Section II, Global Navigation Satellite System (GNSS) outages under highway bridges can negatively impact the localization information provided. Rather than combining differential GNSS with low-cost Intertial Measurement Unit (IMU) information, we saw the necessity of installing a high quality GNSS/INS reference solution.

3) Sensor set: The requirement to serve as data provider as expected for all automation levels led to the decision to install additional redundant sensors, i.e. cameras, lidars and radars, covering a 360 degree FOV. In order to exploit the information available from a state of the art level 2 vehicle, the access to the production vehicle sensor information was also granted.

Production vehicle radars are optimized for Adaptive Cruise Control (ACC) and emergency brake scenarios. This means that production radars are tuned to suppress false positives in order to avoid unmotivated emergency braking maneuvers. For this reason, we preferred to have direct access to raw sensor objects in contrast to the fused and tracked object lists provided by the production vehicle sensors. This enables us to implement our own data-fusion algorithms based on raw data. We can also conduct experiments with improved data fusion algorithms combining vehicle and infrastructure sensors.

We expect that lidar sensors are very likely to be applied in future vehicles providing automated driving above SAE Level 3, and hence we included them in our sensor set.

The production vehicle cameras are neither optimized for the FOV necessary to support fully automated driving.

4) Actuator control: To enable automation, access to the longitudinal and lateral actuators is necessary. We preferred a solution which does not require additional electro-mechanical actuators.

5) HMI: Mounting additional screens which are in the driver's FOV and do not interfere with the production vehicle feedback or its airbags (both is necessary to obtain permission on public roads) is difficult. We favored a solution directly using the available production vehicle screens, except for one additional monitor that was mounted at the back of the passenger seat.

6) Vehicle computers: The nature of the project required the reuse of as much existing open source software libraries as possible, especially regarding middle-ware, sensor drivers, data visualization and validation tools. To offer as much flexibility as possible, two Car PCs were installed, running both Ubuntu and Windows operating systems in a dual-boot setup. To be prepared for deep neural network based image processing, additional GPU power was installed with a state-of-the-art in-car solution. For additional safety, low level control should run on a computer giving real-time guarantees.
Remark: The system design is focused on rapid prototyping solutions and can only be used with a trained safety driver. Implementing a fail-safe and fail-operational hardware and software environment was out of the scope of this project. At the time being, we were not aware of any approved hardware accessible on the market which would enable operation without safety driver. A detailed discussion of an E/E architecture fulfilling the stringent ASIL D requirements is out of the scope of this paper, but the interested reader is referred to other activities targeting this topic previously published by fortiss [4, 26–29].

7) V2X communication: Mobile communication and automotive industries seek for C-ITS solutions for more than a decade. In 2010, the IEEE Standardization Organization (SDO) ratified IEEE 802.11p, the specific amendment to Wireless Local Area Network (WLAN) applicable for C-ITS services. Region specific application related protocol stacks exist to serve the demands of particular markets. Prominent examples are:

- U.S.: Wireless Access in Vehicular Environments (WAVE)
- Europe: Intelligent Transportation System in 5.9GHz (ITS-G5)

3GPP finally published the C-V2X feature in 2017, introduced with Release 14. C-V2X introduces distributed medium access to 3GPP mobile communications under the name Transmission Mode (TM) 4. In WLAN networks, distributed medium access is the fundamental access mode since the first version of the standard. It enables vehicles to coordinate access to the radio channel in a self-organized manner without any central control by a base station. In addition to 3GPP TM 4, latest TM 3 supports network assisted coordination of the V2V communication between vehicles, where the medium access is centrally controlled by a base station. This is facilitated by a separation of C-V2X control and user data, where the control data are handled by the V2N link, while user data are directly exchanged between the vehicles. This network assisted V2V communication allows for a higher spectral efficiency and decreases the probability of data packet collisions. Both systems, IEEE802.11p and 3GPP C-V2X, target the frequency spectrum at 5.9 GHz, which is harmonized almost worldwide for license-exempt operation of C-ITS services. Moreover, both systems share the common attribute to increase transmission reliability through periodic repetition of data transmission.

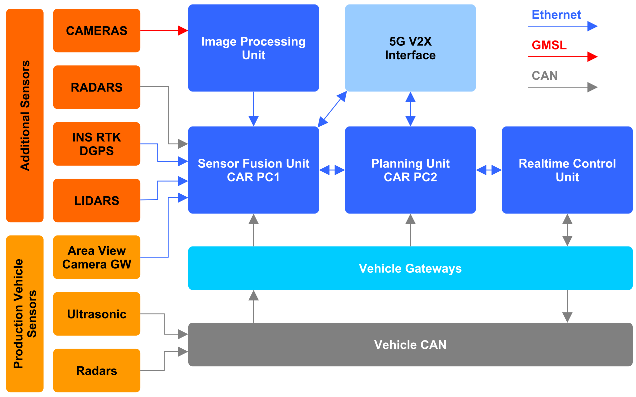

Fig. 2. Schematic hardware architecture of Fortuna. Arrows for Ethernet connections are symbolizing the main data flow, in reality all devices are connected via Ethernet switch.

C-ITS services based on distributed medium access in V2V communications require a sufficient market penetration in order to be successfully applied. In addition, a guaranteed Quality of Service (QoS) is hard to be achieved due to the probabilistic access to the radio channel. If insufficient C-ITS supporting vehicles are present in the road traffic, which holds in particular for the introduction phase of C-ITS, but also for situations with sparse road traffic (e.g. during night time), then V2N communication is considered the preferred choice to provide C-ITS services.

Some C-ITS services are specifically designed for road traffic safety. Common 4G networks are not capable of separating mission critical data transmission from those of Consumer Electronics (CE) applications, which may negatively impact the reliability of operation. The Ultra Reliable Communication Service (URLLC) service provided by 5G is the distinguishing feature of this new technology to support services with strict reliability constraints by providing dedicated system resources for specific purposes.

V. Fortuna's Hardware

Fortuna is a retrofitted production 2018 Volkswagen Passat Variant GTE PHEV. The vehicle is equipped with a 1.4 liter TSI engine with 115 kW and an electric engine yielding 160 kW total system power and 400 Nm maximum torque.

A schematic overview of the hardware architecture is shown in Figure 2. Fortuna has access to additional sensors (cameras, radars, lidars, Inertial Navigation System (INS)) as well as production vehicle sensors (Area View cameras, ultrasonic sensors, radars). The additional cameras are connected to an image processing unit, while the other sensors are connected to a sensor fusion unit. Ultrasonic and radar sensor information of the production vehicle is made available via Controller Area Network (CAN) gateways. A second PC is dedicated to planning tasks and is connected to a real-time control platform, where vehicle control tasks are realized by sending CAN messages to the vehicle gateway. The vehicle gateway allows read and write access for a broad list of information sources available through the CAN bus. Fortuna's 5G communication unit is connected to an Ethernet switch to provide connectivity for all vehicle computers.

In the following, the vehicle modifications and additional hardware are described in detail.

A. Sensors

Lidars: Fortuna uses three Velodyne lidars which are mounted on a roof rack. A VLP-32C with 32 layers is located in a central horizontal position on the roof top and its height can be adjusted using a telescopic bar. It provides a higher point-cloud density in the relevant area close to the horizon and has an extended sensor range of 200 m. Two VLP-16 with 16 layers are positioned at each side of the vehicle roof, which are tilted to scan the areas at each side of the vehicle. The lidar sensor setup allows a 360 deg FOV avoiding blind spots at the sides of the vehicle (see Figures 4 and 5).

Cameras: A total of five Sekonix cameras are mounted behind Fortunas windows to provide a surround view, complementing the production vehicle Area View cameras: Two front facing cameras, one with 60 deg horizontal FOV, and one with 120 deg horizontal FOV, one 120 deg FOV to each side, and one rear camera with 120 deg FOV facing backwards and mounted inside the tailgate. The Sekonix cameras have a resolution of 1928 x 1208 pixels (2.3 Mpixel). The additional camera setup is optimized for the pre-trained perception algorithms provided by Nvidia with the Drive Framework running on Drive PX2. Nevertheless, the system architecture allows to forward raw image data to the data fusion unit, and hence computer vision algorithms can be implemented optionally in Drive PX2 or the data fusion unit.

Radars: 4 Smartmicro UMRR-146 automotive radars are integrated into the bumpers; two facing forwards and two backwards. The Smartmicro automotive radar allows adaptive beam forming and can be switched between straight beams and off-bore squinting beams. The radars have a maximum detection range of about 200 m for truck-size objects, 120 m for cars and 80 m for motorcycles according to [30]. Figure 3 shows an approximation of the maximal FOV realizable when switching between straight and squinting beams, together with an illustration of the resulting FOV of the additional cameras and lidars.

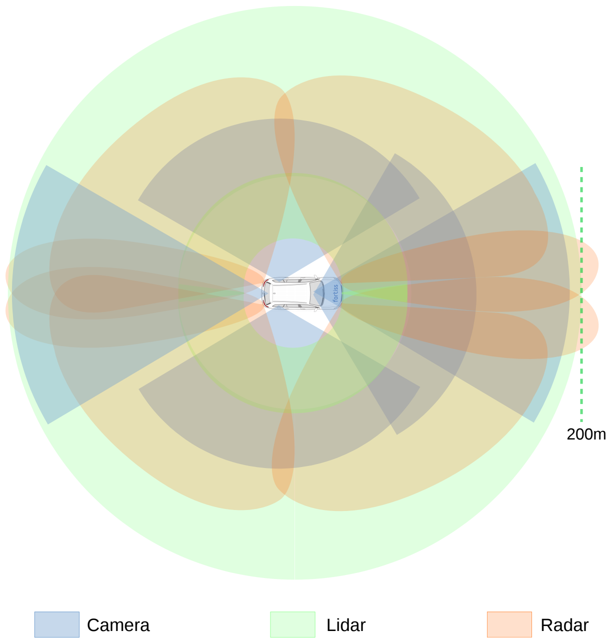

Fig. 3. Illustration of the sensoric field of view of Fortunas non-production sensors (not to scale). Production vehicle sensor information can also be accessed but is omitted in this image.

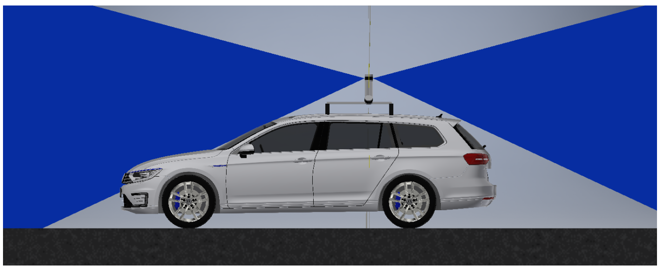

Fig. 4. CAD illustration of the field of view of the central roof lidar (side view). Occlusion effects at the hood are omitted in this illustration.

Inertial navigation system: An iMAR iNAT FSSG-1, a fiber optic gyro (FOG) based GNSS/INS solution serves as high precision reference positioning unit. It supports Real-Time Kinematic (RTK), with a precision of up to 2 cm. Optionally, an external odometer can be mounted to further improve accuracy. We use the AXIO-NET precise real-time service (PED) to obtain GNSS correction data.

B. Additional computing units

The vehicle is equipped with the following set of computers and control units, which are mounted in a rack in Fortunas trunk (see Figure 6).

NVIDIA Drive PX2: The NVIDIA Drive PX2 is a development platform for autonomous driving applications; it is especially suited for deep neural network applications like image processing. The five Sekonix cameras are connected

Fig. 5. CAD illustration of the field of view of the lidars (rear view).

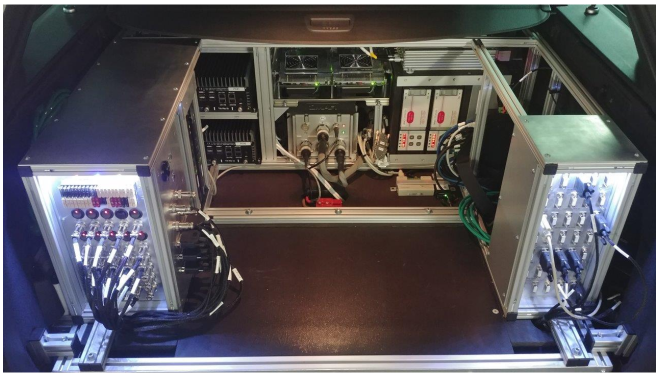

Fig. 6. A view of the trunk of Fortuna with the rack holding the additional devices. The backup battery is hidden under the board. Components are (clockwise from bottom left): Power panel, KVM switches, CAR-PCs, Drive PX2 and iNAT FSSG, MAB II and CAN-GWs, Ethernet switch, CAN panel

to the PX2 via GSML interface.

CAR-PCs: Both CAR-PCs house Intel Core i7-6700TE Quad core processors, 32 GB DDR4 RAM and 512GB SSDs. They are equipped with NVIDIA GeForce GTX 1050 TI GPUs. They are fanless, support 12V power supply with an ignition port for auto shutdown, and have internal backup batteries. They are equipped with LAN, CAN FD, USB, DIO, HDMI and serial interfaces.

dSPACE MircoAutoBox II: For additional safety, the low level vehicle controllers (acting on steering and acceleration interfaces) of Fortuna run on a dSPACE MicroAutoBox II (MAB II) real-time system. The MircoAutoBox is, in contrary to the CAR-PCs, extremely shock and vibration resistant, complying with automotive standards.

Ethernet network switch: All computing units are connected via an industrial 20-port full Gigabit managed Ethernet switch type PLANET IGS-20040MT. It supports virtual LAN (VLAN) to split network traffic into separate groups.

C. Vehicle Gateways

Gateways enable access to production vehicle data.

Fig. 7. The infotainment display showing a visualization of the perception of Fortuna.

Media Gateway: A Media Gateway allows access to the Area View cameras of the production vehicle, supporting automotive Broad-R-Reach Ethernet on the sensor side. This makes it possible to receive images from the 360 deg FOV Area View cameras, including access to the rear view camera during forward driving (non-production vehicle feature).

CAN Gateways: These provide access to the production vehicle CAN on private CAN buses. This way, a subset of production vehicle state information can be accessed without conflicting with the manufacturers intellectual property concerns. For security reasons, the private CAN buses are physically separated into a read-only CAN and a read/write CAN. The gateway which allows write access carries additional actuator limitations to enhance safety of the prototype solution. The information available on the private CAN bus includes (but is not limited to):

- Ultrasonic sensors: distance measurements from sensor set allowing a 360 deg FOV
- Radar: List of detected objects provided by production vehicle ACC system
- Vehicle state information, e.g. speed, acceleration or status of light system
- Interface to control steering, acceleration, brakes, gears and indicator lights

D. Auxiliary components

Backup battery: A secondary 12V backup battery powers the additional hardware and sensors. The power management permits charging the backup battery both via grid charging and via the PHEV's high voltage battery.

Emergency shutdown: For safety reasons, emergency shutdown mechanisms ensure that the safety driver is immediately able to restore the production vehicle mode. Key switches are integrated to activate and deactivate read-only and read/write access to the vehicle interfaces. This avoids unintentional activation of safety critical modes.

E. Human-machine interfaces

Both PCs and the PX2 are connected to two Keyboard Video Mouse (KVM) switches. They facilitate to freely configure the video output to the following displays:

Additional display mounted behind passenger seat: This serves as main display during development.

Infotainment display: The production vehicle display in the center console (see Figure 7).

Head-up display (HUD): Access to the production vehicle HUD enable prototypical implementations of driver alerts as mentioned in Section III.

Additionally, an industrial IEEE 802.11 b/g/n wireless access point allows to connect mobile devices with the in-car network.

F. V2X communication unit

To provide connectivity to the mobile network and to ensure meeting strict reliability and latency constraints in the V2N communication, a prototype 5G terminal provided by Huawei Technologies is installed. The terminal operates at 3.7 GHz carrier frequency and supports a total bandwidth of 100 MHz. Is is equipped with 4 antennas in total, whereof two can be selected for simultaneous transmission, while all four can be used for simultaneous reception. The two transmit antennas allow for beam-forming, where the radio wave can be steered into the direction of the base station to overcome the attenuation effect of path loss at higher carrier frequencies. The multiple reception antennas permit to suppress interferences and to improve the overall reception quality. The 5G terminal can communicate with a prototype 5G base station, which has been set up on our PROVIDENTIA test track. The maximum data rate supported in the link between prototype terminal and base station amounts to 2 Gbit/s, which could successfully be tested under lab conditions.

G. Software

Fortuna's hardware allows rapid prototyping with a variety of software platforms, including ROS [31] as well as Apollo [32]. The Nvidia Drive PX2 supports the NVIDIA DRIVE software. We aim to publish details about Fortuna's software architecture and the experiences with the Apollo platform in a separate paper.

VI. Conclusion and Future Work

We gave insights into the requirements and design decisions we took when setting up fortiss' prototype vehicle Fortuna. We presented a detailed overview of the hardware modifications, which fulfill these requirements.

The localization solution provides ground-truth data and is currently used to calibrate the PROVIDENTIA system. The human-machine interface enables V2X applications and user studies. The sensor set allows redundant detection of the environment with a 360 deg FOV and a range of up to 200 m. It provides both abstracted production vehicle sensor data (object lists) via the CAN interface and high resolution perception data of the additional cameras, radars and lidars. The design also allows prototypical implementations of cooperative automated driving functions thanks to the write access to the vehicle CAN bus.

The 5G terminal is integrated in Fortuna and first connectivity tests with 5G have been successfully performed in the lab, and the way is paved for tests in the PROVIDENTIA test field: The base station is installed and operational, frequency licenses for the operation have been obtained, basic coverage tests are being prepared.

Fortuna is ready to be used on public roads thanks to a special prototype permission which was granted by the registration office. This is valid for both manual and automated operation, the latter with a safety driver. In order to get this approval, a Hazard Analysis and Risk Assessment, following the ISO26262 Part 3, was carried out.

As next steps, detailed communication tests using 5G on the PROVIDENTIA test field will be performed, including measurements of coverage, throughput and latencies for the transmission of data as provided by the PROVIDENTIA system. Findings from evaluation of those measurements will help to specify timing requirements for safety critical applications built on the PROVIDENTIA system.

Acknowledgments

The German Federal Ministry of Transport and Digital Infrastructure supported this work within the project PROVIDENTIA. The financial support is gratefully acknowledged.

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