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AN OVERVIEW OF TEST INFRASTRUCTURE INVESTMENTS ON OPEN ROADS TO TEST CONNECTED AND AUTOMATED VEHICLES

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Abstract *Open road testing is an essential stage of the process of approving driver assistance and other self-driving functions. However several countries have opened their network with or without limitations for autonomous vehicle testing, there are some sections where the infrastructure was designed to support testing. The aim of this article is to give an overview of such open road testing facilities around the world, introducing the main purposes, the used infrastructure (eg. sensor network, communication) and features (eg. data processing, and control functions), and compare them to the planned investments in Hungary.*

Keywords *open road testing, connected and automated vehicles, intelligent transport systems, sensor infrastructure*

1 INTRODUCTION

After test vehicles are proven to be safe in a controlled testing environment, the next step is to prove in a limited public road-testing environment. This pertains to both passenger and commercial vehicles. Some countries have opened their entire road network for testing CAVs. in line with this several countries have implemented C-ITS services for testing V2X communication, and there are a number of smart highway projects, too, but there are only a few locations, where the sensor infrastructure was planned to facilitate CAV testing on open road sections. There are some common features implemented in these projects eg. highly accurate digital maps, radar/LIDAR infrastructure sensors or digital twins. We introduce the latest deployments, and planned investments of this kind of test infrastructure.

2 EXPERIMENTAL PROJECTS

Without a claim to completeness we have selected three interesting and unique trials, with various scopes and concepts. We introduce two smaller scale European sites, that are already in operation since 2017, and an ambitious Chinese project which is under construction. Aside from the differences both

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implementations are using state-of-the-art sensor infrastructure, data fusion, and -procession technologies paving the way for traffic management in the future.

2.1 Germany – Providentia ++ (A9)

Providentia is a research project that has been funded by the Federal Ministry of Transport and Digital Infrastructure (BMVI) since early 2017. From 2020, it has been continued under the name Providentia++ with the Chair of Robotics, Artificial Intelligence and Real-time Systems at the Technical University of Munich's Department of Informatics serving as consortium leader. The project's goal is to research the flow of information between vehicles and infrastructure along the A9 federal highway extending into the urban area, to create a digital twin of the current traffic situation, and from this to develop value-added services. The digital twin will make it possible for connected vehicles to predict which lane the vehicle should use in order to navigate through traffic as smoothly as possible and will help to prevent accidents, as the sensor technology will be able to anticipate hazards (Providentia++, 2022).

In the first phase of the Providentia project, high-resolution cameras and radar systems were mounted on two overhead signs on a test section of the A9 highway (Fig 1. gantry no. 2 and 3). The sensor data was transmitted via 5G, artificial intelligence was used to identify vehicle types and classes, and a digital twin was created with data fusion. An autonomous vehicle was developed that can use the information from the digital twin to independently change lanes on the highway, for example, or to slow down to avoid traffic jams or accidents.

Fig. 1 Providentia phase 1 deployments; source: https://innovation-mobility.com/

Digitally representing traffic, recognizing vehicles, and transmitting data in real time: A key role is played by sensors, perception (with object recognition and tracking, as well as data fusion), and 5G radio technology.

Sensors: to date, near-field cameras for distances of 20 to 250 meters and far-field cameras for distances of 200 to 400 meters have been used on the overhead highway signs, along with radars (which have a range of 300 meters) for both directions. The use of an area scan camera, which allows a 360-degree view, is planned. For the urban environment, which will be the focus of the follow-up project Providentia++, LIDAR systems will also be used. These systems transmit laser beams and represent their reflection in a point cloud. The LIDAR systems that will be used have 128 laser beams and cover 360°. In addition, they have a range of 50 to 70 meters – enough to recognize pedestrians, bicycles, and motorcycles at intersections.

Perception in real time: AI-based algorithms, adaptive open-source software, and neural networks. Vehicles such as passenger cars, trucks, and delivery vans are recognized and labelled accordingly. Modern AI-based algorithms, adaptive open-source software, neural networks for the recognition of objects, and mathematical operations are used. After all the collected data has been fused, the respective objects are recognized and assigned to a point in time. This enables tracking and the allocation of unique IDs.

5G radio technology: C-V2X for communication between vehicles and infrastructure. Communication between vehicles and the external infrastructure takes place by means of the 5G radio standard. There is a fibre optic cable network for data transmission of road-side equipment.

In addition to this basic technology, several tools for data integration and visual representation are used, for example:

Robotic Operating System (ROS): Connecting sensor stations.

ROS is a middleware and library framework for robots. It was invented at the Stanford Artificial Intelligence Laboratory in 2007 and further developed at the Willow Garage robotics institute from 2009. Since 2013 it has been maintained by the Open Source Robotics Foundation (OSRF). Sponsors and supporters are organized in the ROS Industrial Consortium. ROS offers the means of connecting the sensor stations with each other.

CARLA: Open-source simulator for researching autonomous systems.

The virtual "translation" of the real road traffic is made possible by the open-source simulator CARLA, which is used in the study of autonomous systems. The software is able to use and process various sensor data via interfaces, and can also model traffic scenarios. The Robotic Operating System can be integrated over an ROS bridge (Providentia++, 2022).

2.2 Finland/Norway – Aurora (E8) Test Corridor

Most of the automated vehicle tests are currently carried out in snow-free areas. However, there are numerous challenges that arise in Nordic countries when testing autonomous functions in snowy and icy road conditions. Drifting and blowing snow practically blocks the vision of any camera system while causing major difficulties for LiDAR systems as well. On snow-covered roads, the lane markings are not visible either. Further, the availability of satellite positioning is more limited in Arctic areas and magnetic storms, i.e. the Aurora Borealis phenomenon, causes difficulties for GPS (Kotilainen et al., 2021).

The public service platform for testing consists of 10 km of instrumented road section (see Fig. 2.)) along the E8 (sensor technology and information services supporting testing of ITS, CAD and asset management in road traffic, HD map services and Aurora positioning service, correction service, Finnref station). Used sensor technology: vibration, weight, pressure, acceleration, oscillation frequency, road surface slipperiness, measuring and monitoring of the road structure and condition, traffic volumes, and weather conditions.

Fig. 2 Test section near Muonio Finland (2018); photo: Tamás Attila Tomaschek

The test infrastructure consists of access and distribution switches (in equipment shelters) providing tester-specific private VLAN and dedicated ports, as well as the teleoperators' routers; heated equipment shelter, where testers can install their own equipment; electricity, fibre optic network (covering the 10 km road) and internet connection; cable protective pipes under and along the road can be used for installing additional cables if needed; and cable manholes (connection to electricity and fibre) and electric distribution centres. Test equipment can be installed in equipment shelters, masts, poles, as well as in and along the road. On a 1.5 km stretch along the road there are fixed stands on which, for example, marker posts and ploughing poles or the equipment required for testing may be installed (Snowbox, 2018).

2.3 China – Vehicle-road-cloud integration project (Heng Yang, PRC)

Unlike other numerous autonomous driving companies, the Chinese Mogo AI not only focuses on how to make vehicles smarter, but also to make the roads more intelligent. This solution is called "vehicle-road-cloud integration," which means that we add road sensing to the intelligence of the individual vehicle. The data from both terminals of vehicles and roads are uploaded to the cloud to form decisions, then are sent back to the vehicles. In MoGo AI's "Vehicle-Road-Cloud integration" autonomous driving system, road perception and edge-computing devices can timely send what it sees to autonomous vehicles, helping vehicles percept more comprehensive information in advance, thus save more decision-making time to improve safety of autonomous driving. The system can also map urban traffic into a 1:1 digital world, help build city-level traffic digital twin. With a total investment of approximately 500 million yuan, the autonomous driving project cooperated by Mogo and Heng Yang City is the world's largest city-level autonomous driving commercial project so far. The project will deploy more than 10,000 roadside intelligent terminals along 200-km arterial road in Heng Yang City and realize 100% digitalization of all traffic elements (Mogo AI, 2022).

Fig. 3 City-level traffic digital twin; source: www.zhidaohulian.com

The first phase of the project started in September 2021., where a 38-kilometre-long intelligent road will be deployed and put into use by nearly 1,000 self-driving vehicles on city streets (see Fig. 3). The line-up includes L4 robobuses, robotaxis, self-driving shuttle buses and other public service vehicles including ones used for fire-fighting, street sweeping, distributing and emergency medical services. The company also builds and operates a cloud-based urban traffic management platform to provide fleet scheduling and lane-level information data services (Road Traffic Technology, 2021).

3 PLANNED TEST INFRASTRUCTURE IN HUNGARY

3.1 M76 Smart Highway

The new M76 Smart highway will provide direct connection between the ZalaZONE proving ground and Budapest. Its total length will be 52.5 km, with two lanes in each direction. One of the extraordinary features of this Smart highway will be the 10 km long section that will be dedicated for high-speed testing. In case of extra high-speed test, the 10 km section can be separated from other public traffic with mobile barriers, and public traffic can run with a lower capacity (2×1 lanes) using Road zipper technology to separate the two directions. According to the plans, the whole highway will be covered with C-ITS technology, including ITS-G5 and 5G cellular communication networks. In the highway's smart rest area, full coverage of cloud service will be supporting the data management. Sensor deployment along the highway is also planned, including radars, LIDARs, and cameras. In the M76 infrastructure, more smart solution could be implemented. The potential planned equipment and features are the following: fibre optic telecommunication network along the whole motorway, cameras for incident detection, LIDAR and radar sensors for traffic monitoring and incident detection, road surface sensors, and weather stations, Variable Message Signs, C-ITS services, DGPS coverage, High Definition 3D map of the whole motorway, LTE/5G, and ITS-G5 coverage on the whole motorway, Internet connection on dedicated sections via Wi-Fi. The motorway is already under construction, it is planned to be in operation from Q4 2024 (Tihanyi et al., 2021).

3.2 Central System project

There is an ongoing smaller scale project focusing on realizing a transport system using the highest-level state of the art technology to develop and demonstrate a holistic solution to support and operate autonomous vehicles in cooperation with infrastructure elements. The proposed solution builds up the global environment model externally in a cloud and supports the individual vehicles with a comprehensive world model or even can control them. The system will collect all information from both vehicle and infrastructure side and fuse them together in a cloud based, real time digital twin (Figure 4.). Cloud based map content:

- Static map (3D representation, vectorised data, material properties)
- Semi static and semi dynamic content (like weather or lighting conditions, road conditions...)
- Full dynamic data (vehicles, pedestrians and all relevant dynamic information)

The project will provide a platform for road infrastructure related cloud based services for connected and automated vehicles. In this particular project the consortium members plan to realize the system in bigger scale, extend the functionality to a certain level by implementation of particular services. (Tettamanti et al., 2021).

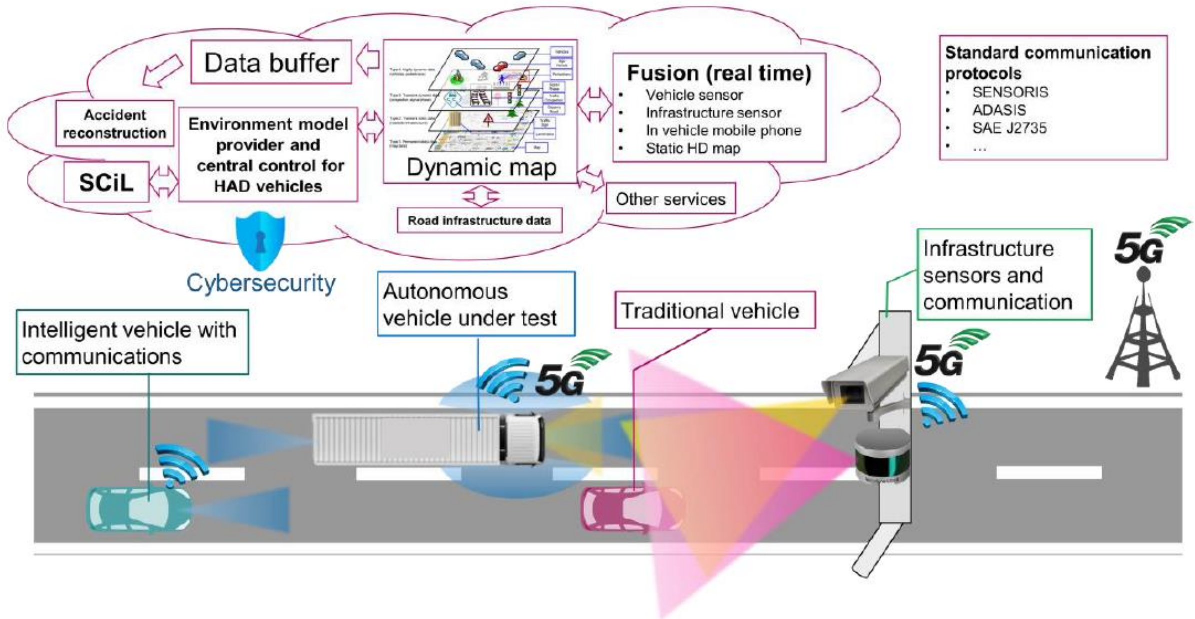

Fig. 4 Central System Concept (Tettamanti et al., 2021)

The first sensor infrastructure set would be installed along the common section of M1-M7 highways near to Budapest. This sensor infrastructure is going to be a small scale implementation of the sensor infrastructure planned to be installed in the frame of the M76 smart highway project.

4 CONCLUSIONS

In today's mainstream for operation of highly automated vehicles the main environmental model for vehicle guidance is generated based on the ego vehicle's perception system and extending the own local sensor signals with infrastructure's and other vehicle's information. In line with this, the proposed Hungarian pilot builds up the global environment model externally in a cloud and supports the individual vehicles with a comprehensive world model or even can control them. The system will collect all information from both vehicle and infrastructure side and fuse them together in a cloud based, real time digital twin, alike to the other examples.

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