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Autonomous Driving in the iCity—HD Maps as a Key Challenge of the Automotive Industry

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ABSTRACT

This article provides in-depth insights into the necessary technologies for automated driving in future cities. State of science is reflected from different perspectives such as in-car computing and data management, road side infrastructure, and cloud solutions. Especially the challenges for the application of HD maps as core technology for automated driving are depicted in this article.

1. Introduction

The vision of autonomous vehicles has a long history. In the year 1925, a prototype of a radio-controlled vehicle was demonstrated by the "Linrrican Wonder" in New York [1]. Since then, autonomous driving has been a topic of science fiction and, more recently, within engineering science. Big car manufacturers and players in other industries have now announced their intention to introduce fully automated cars within the next 10 years.

Autonomous driving is thus on its road to market entry. It requires a set of high-end technologies in both cars and infrastructure that are comprehensively connected or even integrated. A key technology for autonomous driving is the real-time high-definition (HD) map. This technology covers three main challenges for autonomous driving.

The first challenge addressed is the capability of a vehicle to localize itself with high precision in relation to its environment. The second challenge is to solve the problem of recognition and reaction to events appearing on the road beyond the reach of onboard sensors, in a range of more than 200 m ahead or around corners. The third challenge concerns the vehicle's capability to drive in accordance with the needs of passengers and other traffic participants [2].

Until now, maps in cars have been used mainly for navigation purposes, along with applications around points of interest. The resolution of these maps is not precise enough for autonomous driving. In addition, current maps do not meet the requirement of real-time information (i.e., live maps) and do not provide sufficient information for autonomous driving. Especially in urban environments with high traffic density, the requirements for safe, fully automated driving are tremendous—not only in terms of vehicle specifications but also in terms of infrastructure specifications. A good overview of European progress in this field of research gives the European roadmap smart systems for automated driving [3].

This article provides insights into the research of applied science institutions aimed at the realization of autonomous driving, based on HD maps in the city of the future: the iCity.

2. High-definition (HD) maps and automated driving

Fully automated driving requires an intelligent control system

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consisting of highly performant sensor and robotic technologies. The requirements for a technical system must obviously reflect the capabilities humans need to drive a car. Simply identifying where the roads are is insufficient for autonomous driving. A robotic car must have the ability to detect and avoid obstacles. In addition to immovable obstacles, roads contain dynamically moving traffic participants such as other cars and—particularly in urban areas—the more fragile pedestrians and cyclists. Especially in critical situations, the detection and control system of an autonomously driven vehicle must have fast reaction times. A robotic car requires a range of sensor technologies such as sonar devices, stereo cameras, lasers, radar, and car-to-X communication. All these technologies have different reaches of view, and each technology has a dedicated purpose that is comparable to one or more of the five human senses. The main "sense" of a robotic car is the LiDAR (an acronym for light detection and ranging), a laser-based process that senses objects in the near-field environment of the car [4].

Fig. 1 shows a point cloud image of a LiDAR device mounted on a self-driving car.

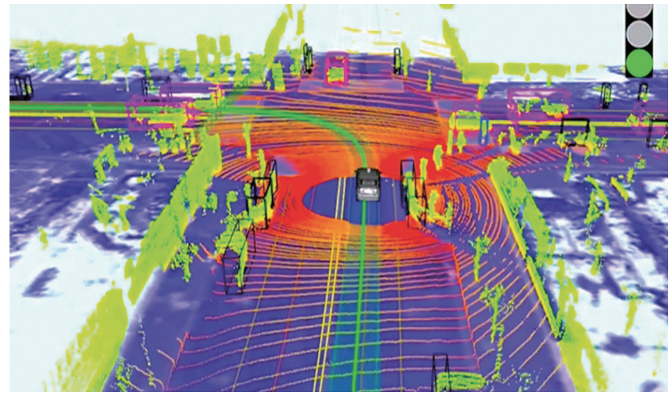

Fig. 1. A point cloud image of a vehicle approaching an intersection illustrates the complexity of data collected by a Velodyne LiDAR [5].

The importance of a LiDAR system comes from its accuracy, which is up to a range of 100 m, and its rotational ability of 360 degrees. With more than two million readings per second, a LiDAR system provides high-resolution information on the environment around the car.

The second core sense of a robotic car is the Global Positioning System (GPS), which allows a rough localization of the car. This localization is the basis for state-of-the-art navigation systems with 3D topographic displays, rendered with virtual reality buildings and near-time traffic information. Although it is an advanced technology, the accuracy of GPS is insufficient for the next generation of highly automated driving cars. In a best-case scenario, GPS achieves an accuracy of up to 5 m; however, autonomous driving requires accuracy on the centimeter level.

This need for accuracy means that a robotic car requires additional senses that have to be fused in order to provide a real-time high-resolution image of the car's environment. Radar, ultrasonic sensors, and stereo cameras are important "feelers" of a car's immediate surroundings. This fusion of sensor data and GPS data enables the positioning of a car's location to within 10 cm.

In addition to high-precision localization, vehicle-to-infrastructure and vehicle-to-vehicle communication provides further information that enhances the reach of perception of the surrounding environment to up to 1 km. By imagining millions of cars acting as connected, mobile detection devices, with information hubs collecting sensor data and providing these to cloud solutions, creativity for new business models will be stimulated. For this reason, the consortiums of Audi, BMW, and Daimler have acquired the Nokia spinoff, HERE. This deal gives these car manufacturers access to leading-edge navigation software to drive their next generation of autonomous cars.

The advantage of HERE, compared with its competitors, is its vast amount of data, collected by racking up more miles than anyone else. Exploiting this logic by applying a crowdsourcing business model, based on every car as a rolling measuring machine, will increase the quality of the evolving cloud service toward perfection. In addition to HERE, companies such as Bosch, TomTom, Uber with deCarta, Google, and Apple have joined the quest for autonomous driving.

One of the most promising strategies for autonomous driving is the application of simultaneous localization and mapping (SLAM) algorithms. The reconciliation of real-time gathered data from onboard sensors with cloud-based HD map data provides a virtual image of the car's vicinity to landmarks. This allows an exact determination of location and relation to other road users. SLAM technologies place high requirements on computing power and data transmission. At the moment, the main bottlenecks are the following:

- Data collection: One hour of drive time corresponds to one terabyte of data.
- Data processing: Interpreting one terabyte of collected data by means of high computing power requites two days to come up with usable navigation data.
- Data transmission: Although today's available LTE (4G) allows data transmission at 100 $Mbit \cdot s^{-1}$, 2.2 $Gbit \cdot s^{-1}$ are required. However, 5G enables 5 $Gbit \cdot s^{-1}$ and will be market-ready in 2020+.
- Latency time: For real-time execution, latency must be lower than 10 ms—which requires high-performance computing onboard the vehicle.

The current state of research on these problems demonstrates the capability of automated driving by means of prototypes. New players and research institutes such as Fraunhofer-Gesellschaft cooperate with car manufacturers and information technology companies on solutions that also take new propulsion concepts into consideration [6]. The progress of the different research initiatives must be considered as differentiated. New, upcoming tech firms operate differently than tier one suppliers of the automotive industry, considering all points on the original equipment manufacturer (OEM)'s requirements list. With the integration of Android or CarPlay with embedded systems, new tech firms develop automated driving solutions in an agile and flexible way. Of course, this development is still in preliminary stages; however, for the shift toward full automation, software becomes the driving force. Thus, corporate venturing in this field becomes more and more important, in order to secure access to key knowledge and technology—as the Nokia HERE case proves.

An analysis of the progress that has been achieved thus far with the main automated driving initiatives reveals interesting findings. For example, Google is not as close to a marketable solution as the media implies. Multiple thousand-mile trips with a small fleet of semi-robotic cars are far from sufficient to obtain data for fully automated driving. In comparison, Nokia HERE has a fleet of more than 400 cars equipped with LiDAR and four wide-angle 24-megapixel cameras, and has mapped more than three million kilometers. Additional data for the development of an HD map comes from a built-in gyroscope and high-end GPS. The data fusion of these different sources is done by sensor data fusion using high-performance computing power. The storage of the gathered data requires high-speed hard drives with multiple terabyte capacity. The data transfer from car to central cloud computers is done by the exchange of the complete hard drive. To date, this is the fastest and safest way. The data is used for rendering roads and for building up HD maps. Based